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NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND



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PHYSIOLOGICAL RESPONSES TO WEARING THE HELICOPTER AIRCREW INTEGRATED LIFE SUPPORT SYSTEM (HAILSS) IN HOT ENVIRONMENTS

by

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8 August 2000

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DEPARTMENT OF THE NAVY
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
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| 14. ABSTRACT Individuals wearing encapsulating garments require auxiliary cooling systems to sustain physical and cognitive performance when exposed to high temperatures or workloads. The Helicopter Aircrew Integrated Life Support System (HAILSS) is designed to minimize thermal problems by incorporating normal flight suit functions with protective functions (fire, chemical and biological warfare (CBW), and cold water immersion) in a single, integrated clothing ensemble. This study evaluated the effectiveness of the HAILSS cooling concept by comparing heat loads incurred while performing up to 6 hr of physical work in either HAILSS or the current A/P22P-9(V) CBW protective ensemble. This study exposed seven test subjects (six male, one female) to six experimental trials each. Subjects wore the HAILSS (h20, h75) and CB (m20, HAILSS" N" 75" 35" a) Need for head ventilation b) Airflow through breathing valve adequate but saliva a problem, "mouth too wet" M.L.nt moderate physical work (40% of an individual's maximum oxygen uptake) and cognitive tasks. In addition, each subject had one exposure using HAILSS without the chemical protective AR-5 hood (h75n) and another employing HAILSS with cooled ventilation air (24°C inlet air temperature) (h75c) in the hot/humid condition. Test results indicated 20% RH trials lasted significantly longer (p<0.01) and were significantly less stressful (p<0.05) than 75% RH trials based on various physiological parameters. Increasing heat removal by ancillary cooling brought the level of heat strain experienced in the HAILSS assembl at 75% RH to roughly that of Mk 1 or HAILSS at 20% RH. HAILSS or Mk 1 without ancillary cooling was demonstrably more stressful to wear at 75% RH than at 20% RH. Operational mission performance would likely degrade at this higher RH without active cooling. These results demonstrate that ambient relative humidity significantly affects heat removal even in totally encapsulated protective clothing ensembles. | | | | | |
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SUMMARY

Individuals wearing encapsulating garments require auxiliary cooling systems to sustain physical and cognitive performance when exposed to high temperatures or workloads. The Helicopter Aircrew Integrated Life Support System (HAILSS) is designed to minimize thermal problems by incorporating normal flight suit functions with protective functions (fire, chemical and biological warfare (CBW), and cold water immersion) in a single, integrated clothing ensemble. This study evaluated the effectiveness of the HAILSS cooling concept by comparing heat loads incurred while performing up to 6 hr of physical work in either HAILSS or the current A/P22P-9(V) CBW protective ensemble. This study exposed seven test subjects (six male, one female) to six experimental trials each. Subjects wore the HAILSS (h20, h75) and CB (m20, m75) ensembles in two environments (35°C/20% relative humidity (RH) (hot/dry), 35°C/75% RH (hot/humid)) while performing intermittent moderate physical work (40% of an individual's maximum oxygen uptake) and cognitive tasks. In addition, each subject had one exposure using HAILSS without the chemical protective AR-5 hood (h75n) and another employing HAILSS with cooled ventilation air (24°C inlet air temperature) (h75c) in the hot/humid condition. Test results indicated 20% RH trials lasted significantly longer ($p < 0.01$) and were significantly less stressful ($p < 0.05$) than 75% RH trials based on various physiological parameters. Increasing heat removal by ancillary cooling brought the level of heat strain experienced in the HAILSS assemble at 75% RH to roughly that of Mk 1 or HAILSS at 20% RH. HAILSS or Mk 1 without ancillary cooling was demonstrably more stressful to wear at 75% RH than at 20% RH. Operational mission performance would likely degrade at this higher RH without active cooling. These results demonstrate that ambient relative humidity significantly affects heat removal even in totally encapsulated protective clothing ensembles.

Contents

| | <u>Page No.</u> |
|-------------------------------------|-----------------|
| Introduction | 1 |
| Methods..... | 2 |
| Materials | 2 |
| Subjects..... | 3 |
| Instrumentation | 4 |
| Experimental Methods..... | 5 |
| Physiological Indices | 7 |
| Statistical Analysis..... | 7 |
| Results | 8 |
| Discussion..... | 10 |
| Conclusions..... | 15 |
| References..... | 17 |
| Appendix | |
| Subject Postexposure Comments | 19 |
| Distribution | 45 |

Figures

| | <u>Page No.</u> |
|---|-----------------|
| 1. HAILSS baseline ensemble configured for present study | 19 |
| 2. USN A/P22P-9(V) (Mk 1) ensemble configured for present study | 20 |
| 3. Schematic drawing of the cooling system used during h75c exposures | 21 |
| 4. Location of thermocouples and heat flux transducers | 22 |
| 5. Heart rate, rectal and mean skin temperature data from a typical subject's..... exposure | 23 |
| 6. Regional skin temperatures during preexposure rest period | 24 |
| 7. Mean rectal temperature (T_{re}) changes for each experimental clothing..... configuration as a function of exposure time | 25 |
| 8. Mean changes in skin surface heat flux and temperature occurring 60 min | 26 |
| into exposures | |
| 9. Changes in rectal (top) and mean skin (bottom) temperatures..... | 27 |
| 10. Changes in arm (top) and thigh (bottom) temperatures..... | 28 |
| 11. Mean peak heart rate during the first three exercise periods of each exposure..... by configuration | 29 |
| 12. Minimum heart rates observed during the preexposure rest period and the | 30 |
| first three exposure rest periods | |
| 13. Mean changes in forehead (top), nape of neck (middle), and occipital neck | 31 |
| (bottom) temperatures by configuration | |
| 14. Percent change in plasma volume by configuration relative to m75 results..... | 32 |
| 15. Heat flux measured at various body regions by configuration | 33 |

Tables

| | <u>Page No.</u> |
|---|-----------------|
| 1. Experimental test conditions used in study | 2 |
| 2. Clothing items associated with each test ensemble..... | 3 |
| 3. Physical characteristics of test subjects..... | 4 |
| 4. Observed subject tolerance and physiological temperature changes during..... experimental exposures | 9 |

INTRODUCTION

Helicopter aircrews are exposed to a variety of stressors (e.g., heat, humidity, physical and cognitive workloads) and potential hazards (e.g., cold water ditching) while performing normal peacetime operations. Combat adds significantly to aircrew burdens in terms of physical and psychological demands and added risks (ballistic threats, exposure to chemical and biological warfare (CBW) agents). Personal protective equipment assists aircrews in meeting these demands but also adds to thermal burdens by imposing additional bulk and thermal insulation on the individual. One possible consequence of these cumulative stresses is hyperthermia, a potentially dangerous condition which can severely degrade mission performance and, in extreme cases, cause fatalities.

Specific garments intended to provide protection against fire, CBW threats or immersion hypothermia (in case of ditching) can retain large quantities of body heat due to their impermeable nature. Semipermeable CBW protective garments such as the U.S. Navy (USN) Mk 1 using carbon-impregnated fabrics reduce this heat burden because air passing through the clothing can convect heat out of the garment. Unfortunately, this permeability can be exploited by certain types of CBW agents. Protection against multiple threats currently requires individuals to wear multiple garments over each other which adds undesirable bulk and leads to additional heat retention. Body heat trapped within these encapsulating garments needs to be removed if the garment user is to adequately perform required tasks, especially when users are physically active. These cooling requirements may increase substantially in the future because advanced warfighting concepts envision routine use of CBW protection.

The Helicopter Aircrew Integrated Life Support System (HAILSS) is a protective garment concept designed to minimize thermal problems by incorporating normal flight suit functions with operational protective functions (fire, CBW, and cold water immersion) into a single, integrated clothing ensemble which provides acclimitization (reference 8). It consists of a coverall made from a new trilaminate material, head-eye-respiratory protection, and a portable blower system to remove body heat by ventilating the space between the suit and the wearer. The present study evaluated the effectiveness of the HAILSS cooling concept by comparing heat loads incurred while performing up to 6 hr of light work in either HAILSS or the current A/P22P-9(V) CBW protective ensemble. Experiments were intended to test the following hypotheses: 1) HAILSS will allow only a minimal rise in T_{re} while performing a light work/rest cycle regardless of ambient relative humidity; 2) using the AR-5 CBW hood with HAILSS has negligible effects on subject tolerance of test conditions; and 3) using HAILSS will increase the capacity to tolerate mission-related workloads in high heat environments.

METHODS

This study was designed to test HAILSS under representative environmental conditions by exposing each test subject to six experimental trials run in differing random orders. The high humidity environmental conditions reflect a hot-wet standard thermal environment representing tropical conditions (defined in Air Standardization Coordinating Committee (ASCC) AIR STD 61/62 (reference 1)). Test conditions h20, h75, m20, and m75 compared heat stress produced by HAILSS with CBW heat stress. The additional exposures, h75n and h75c, assessed the role of CBW head protection (AR-5) and ancillary cooling on physiological heat stress. Table 1 shows the experimental conditions for each of the experimental trials.

Table 1: Experimental Test Conditions Used in Study

| Test Condition | Garment | Nominal relative humidity (%) | AR-5 hood? | Ventilation air flow? | Nominal inlet air temperature (°C) |
|----------------|-------------|-------------------------------|------------|-----------------------|------------------------------------|
| h20 | HAILSS | 20 | Yes | Yes | 35 |
| h75 | HAILSS | 75 | Yes | Yes | 35 |
| h75n | HAILSS | 75 | No | Yes | 35 |
| h75c | HAILSS | 75 | Yes | Yes | 24 |
| m20 | A/P22P-9(V) | 20 | Yes | N/A | N/A |
| m75 | A/P22P-9(V) | 75 | Yes | N/A | N/A |

MATERIALS

Two clothing ensembles, the HAILSS baseline ensemble (figure 1) and USN A/P22P-9(V) (Mk 1) (figure 2), were evaluated in this study. The Mk 1 was chosen as the study baseline ensemble because it is currently fielded in the Fleet, allowing a comparison between HAILSS and the current Naval aviation CB ensemble. Table 2 shows the various clothing components comprising each ensemble. The Mk 1 outer garment and liner are fabricated from permeable material which allows evaporating sweat to passively cool users without an ancillary blower system. HAILSS is actively ventilated via a man-mounted blower system. Ventilatory air enters the garment at the level of the umbilicus and passes through tubing along both legs to just above ankle level. Exiting the tubing, ventilatory air passes upward through a nylon mesh spacer liner covering the entire garment inner surface. Valves located on the ventral forearm surfaces cause ventilatory air to pass along the torso and arms before exiting the garment. Butyl rubber wrist and neck seals prevent leaks at these points while booties seal the ankles and feet. Booties are normally intended to be fitted to a single individual and would be heat sealed to the pant leg to prevent leakage of ventilatory air and penetration of CBW agents. As only three complete baseline HAILSS ensembles were available for testing, however, booties were attached with duct tape to the pant leg. This permitted fitting to multiple individuals while still preventing ventilation air from leaking out of the garment. Hand protection for both the HAILSS and Mk 1 consisted of an innermost cotton glove, a butyl rubber glove, and a Nomex flight glove on top. The middle and ring fingers on all three left gloves were cut off to allow access to the finger tips for application of a blood pressure cuff and pulse oximeter sensor. HAILSS was also tested without the AR-5 to

assess how the AR-5 affects heat tolerance. In addition, one experimental condition involved replacing the SAB-87 blower unit with cooled air ($25.4 \pm .5^{\circ}\text{C}$) blown into HAILSS. Cooling was accomplished by passing ambient air through tubing immersed in a chilled water bath (figure 3).

Table 2: Clothing Items Associated with each Test Ensemble

| Garment | Components |
|-------------------------------------|--|
| HAILSS | <ul style="list-style-type: none"> • flight suit coverall made of a butyl-rubber and nomex trilaminate material • booties worn inside flight boots • latex rubber seals at the neck and wrist • portable blower system (Austrian Army SAB-87) ventilating the coverall by blowing filtered air through a polyester spacer fabric, removing body heat primarily through evaporation of sweat • AR-5 head, eye, respiratory CBW protective ensemble (or "hood") worn under a regular flight helmet • protective glove and footwear systems • nomex long underwear and socks |
| A/P22P-9(V) CBW protection ensemble | <ul style="list-style-type: none"> • Mk 1 charcoal-impregnated coverall with booties • standard CWU-27/P flight suit • AR-5 protective hood • standard flight boots and helmet • protective glove and footwear systems • cotton underwear |

SUBJECTS

Seven healthy subjects, one female and six males, volunteered to participate after being fully informed of the details of the experiment protocol and associated risks. Table 3 lists the physical characteristics of the subjects. Body surface area (SA) was calculated from the height and weight of each subject. Maximal oxygen uptake ($\dot{V}_{\text{O}_{2\text{max}}}$) was measured on a recumbent bicycle ergometer (model EC-3700, Cat Eye Co., Osaka, Japan) using a 1-min incremental exercise protocol with 25 W/min increments (reference 10).

Table 3: Physical Characteristics of Test Subjects

| Subject | Gender | Age (years) | Height (m) | Weight (kg) | Surface Area (m ²) | Ergometer workload (Watts) |
|---------|--------|-------------|------------|-------------|--------------------------------|----------------------------|
| 1 | m | 25 | 1.83 | 77.9 | 1.94 | 66 |
| 2 | f | 26 | 1.68 | 66.5 | 1.75 | 30 |
| 3 | m | 25 | 1.73 | 80.2 | 1.94 | 75 |
| 4 | m | 37 | 1.8 | 80.5 | 2 | 50 |
| 5 | m | 39 | 1.83 | 73.2 | 1.94 | 50 |
| 6 | m | 47 | 1.68 | 68.9 | 1.78 | 65 |
| 7 | m | 34 | 1.75 | 70 | 1.85 | 95 |
| mean | | 33.3 | 1.76 | 73.9 | 1.89 | 61.6 |
| SEM | | 3.2 | 0.02 | 2.2 | 0.03 | 7.9 |

INSTRUMENTATION

Two type T thermocouples (model RET-1, PhysiTemp, Clifton, NJ) inserted 10 cm anterior to the anal sphincter measured rectal temperatures during exposures. Seven type T thermocouples fabricated of 36 AWG (0.16 mm dia.) special limit of error wire with exposed welded beads measured skin temperatures at the upper left chest (T_{chest}), upper right arm (T_{arm}), anterior thigh (T_{thigh}), lateral shin (T_{shin}), nape of the neck (prominence of the 7th cervical vertebrae, T_{nape}), occipital surface of the neck (superior border of the nuchal furrow, T_{occ}), and the middle of the forehead (T_{fore}) (figure 4). These sites were used to calculate a mean weighted skin temperature (reference 7) and also identify potential hot spots under the CBW hood. In addition, expiratory airstream temperatures were measured immediately beyond the lips within the AR-5 mask with two 44 AWG (.05 mm diameter) type T thermocouples. Thermocouple voltage signals were linearized with thermocouple signal conditioners (model TC.4, Opto, Huntington Beach, CA) and the linear output processed with an A/D board (model 2831, Data Translation, Marlboro, MA). The temperature measurement system was calibrated at two points with a constant temperature (29.7718°C) Gallium cell (model 17402, Yellow Springs Instruments, Yellow Springs, OH) and a zero-point (0°C) cell (model K140-4, Kaye Instruments, Bedford, MA). Skin surface energy flux was measured at five sites (upper left chest (HF_{chest}), upper right arm (HF_{arm}), anterior thigh (HF_{thigh}), lateral shin (HF_{shin}), nape of the neck (HF_{nape})) with heat flux transducers (model FR 025 TH44018, Concept Engineering, Old Saybrook, CT) interfaced with isolated wideband mV input signal conditioners (model 3B40, Analog Devices, Norwood, MA) and an A/D board (model 2831, Data Translation, Marlboro, MA). These measurements quantified energy transfer across the skin surface both locally and as a weighted average over the entire skin surface (analogous to the mean weighted skin temperature). Heat flux transducers were calibrated based on the technique of Iwamoto, et al. (reference 3). Heart rate was monitored on a VSM-1 electrocardiograph (ECG) monitor (Physio-Control, Redmond, WA) and pulse oximeter (model 8600, Nonin Medical Inc., Plymouth, MN). Blood pressure was monitored with a Finapres finger blood pressure system (Finapres model 2300, Ohmeda, Engelwood, CO). Clothed and nude body weights were measured with an electronic scale accurate to ± 50 g (model FV-150K, A&D Ltd., Tokyo, Japan). Dry bulb ($T_{\text{db, p}}$), wet bulb ($T_{\text{wb, p}}$), and WBGT ($WBGT_p$) preparation room temperatures were monitored during subject dressing (Wibget model RSS-214, Reuter-Stokes,

Canada). Chamber dry bulb ($T_{db, c}$) and wet bulb ($T_{wb, c}$) temperatures was measured with 36 AWG type T thermocouples with the wet bulb fabricated from cotton gauze. Airflow rates were measured along the inlet hose of the HAILSS ensemble (Ventilation Measurement Module model VMM-402, Interface Associates, Aliso Viejo, CA). It was assumed that outlet airflow was symmetrically distributed between the two outlet valves. HAILSS dry bulb inlet ($T_{db, in}$) and outlet ($T_{db, out}$) airstream temperatures were measured with 40 AWG type T thermocouples. HAILSS wet bulb outlet ($T_{wb, out}$) temperatures were measured with 40 AWG type T thermocouples wrapped in cotton gauze. Obtaining HAILSS inlet wet bulb measurements was not feasible because maintaining a continuous supply of water for the gauze was impractical. Attempts to measure metabolic rates failed because of persistent difficulties in obtaining reliable respiratory flow rates. Securing airtight seals between the face and AR-5 respiratory mask proved to be a daunting task.

EXPERIMENTAL METHODS

Experimental exposures: Each subject began their exposures at roughly the same time (morning (~8 AM) or afternoon (~1 PM)) each day they participated. A brief physical exam and medical history was conducted when subjects entered the laboratory dressing area to begin each trial. Mean ambient conditions maintained inside this preparation area were $T_{db, p} = 21.8 \pm .4^{\circ}\text{C}$, $T_{wb, p} = 13.8 \pm 1.2^{\circ}\text{C}$, and $WBGT_p = 16.1 \pm 1.5^{\circ}\text{C}$. $T_{db, p}$ and $T_{wb, p}$ measurements did not vary significantly between trials though $WBGT_p$ during m20 trials was significantly higher by $1.9 - 2.9^{\circ}\text{C}$ ($p < 0.05$) than other configurations. Reason for this $WBGT_p$ difference are unclear. Blood samples (2 vials, 7 mL each) were drawn for determining percent changes in lactic acid concentration ($\% \Delta LA$) and plasma volume ($\% \Delta PV$) (using the method of Dill and Costill (reference 2)) over the course of the exposure. Seminude weight (with underwear and rectal probes) ($m_{i, nude}$) was obtained after subjects inserted their rectal probes. Four ECG electrodes attached to the upper torso were adjusted to obtain the clearest signal on at least 2 ECG leads. Skin thermocouples and heat flux transducers were then taped to the subject (Transpore tape, 3-M, Minneapolis, MN) with care being taken not to place sensors over any tape. The subject was then dressed in the remaining HAILSS or CBW clothing items. The pant legs were placed inside the boot top and taped into position in an attempt to minimize air leaks without heat sealing the ankle seam. Forehead and neck thermocouples and the neck heat flux transducer were taped onto the skin surface just prior to donning the AR-5 and helmet. These sensors were taped into place immediately prior to donning the helmet when not using the AR-5. A finger blood pressure cuff and transcutaneous oxygen sensor were taped to the left middle and ring finger, respectively, after dressing was completed. Subjects began a 20 min preexposure rest period after donning all clothing items and attaching all instrumentation sensors. Data collection began at the $t = -20$ min mark. The SAB-87 blower maintained suit ventilation during HAILSS preexposure rest periods. Garment ventilation was temporarily halted at $t = -1$ while obtaining clothed weight ($m_{i, clothed}$) immediately prior to subjects entering the chamber to begin experimental exposures.

Subjects entered the environmental chamber at $t = 0$ and began a series of up to 12 consecutive rest/work cycles. Air temperatures were fixed at $35.3 \pm 0.7^{\circ}\text{C}$, $WBGT = ^{\circ}\text{C}$, and relative humidity equaled either 20% or 75% depending on the specific test being run on a given day. The initial rest period lasted 35 min (estimated metabolic rate = 139 W assuming metabolic

output for typing (reference 5)) and allowed time for connecting all leads and making final adjustments. Immediately following this preliminary work, subjects performed a series of computer-based cognitive tasks (lasting approximately 15 min). A test of perceived exertion (NASA TLX test battery) was administered at the end of the cognitive test battery after which subjects were permitted to rest for the remaining time in the initial 35 min period. NASA TLX tests assess the relative stress each task (cognitive or physical) imposes on the individual. Pedalling the bicycle ergometer at the predetermined workload ($\sim 40\% \dot{V}_{O_{2\max}}$) (table 3) commenced at the end of the initial 35 min rest period and lasted 10 min (estimated metabolic rate = 420 W (reference 10)). Each subsequent rest/work cycle consisted of 20 min of rest followed by 10 min of physical work with subjects performing approximately 15 min of computer-based cognitive tasks during each rest period. These rest/work patterns produced an average mean time-weighted metabolic rate of 221 W over the first three cycles. Cognitive tasks involved simple grammatical and mathematical processing, numerical and pattern recognition, and spatial reasoning derived from the Essex Delta Test Battery. Cognitive performance was assessed on the basis of percent correct answers, response time, and average task duration. In addition, rest periods began and ended with subjects completing a NASA TLX test. No TLX test was completed immediately after subjects entered the environmental chamber (start of the first rest period) because it was assumed that subjects experienced negligible stress during the preexposure rest period. Final TLX tests assessing stresses experienced at the end of exposures were completed while subjects cooled down outside the chamber. The unacceptable alternative was to insist that subjects complete final TLX tests while exposed to high environmental chamber temperatures after exceeding the experiment's physiological termination criteria.

Subjects sat on the ergometer seat throughout the entire exposure period. Cognitive tasks were performed by having subjects pivot to their right while remaining seated and a computer keyboard and monitor positioned in front of them. Brief moments to stand and stretch in place were permitted at the beginning and end of rest periods. Subjects were provided water *ad libitum* but no food was allowed.

In addition to completing repeated NASA TLX tests, subjects were asked to subjectively rate their comfort, sweating, and fatigue, and temperature on a seven point scale every 15 min. Comfort, sweating, and fatigue were reported using a scale of increasing distress (e.g., for fatigue: 1 = very rested, to 7 = extremely exhausted) and temperature was reported as 1 = very cold, 4 = neutral, to 7 = very hot. Both these subjective measurements and NASA TLX results will be published in a subsequent report.

Chamber exposures terminated when subjects either: (a) completed 12 rest work cycles, (b) requested removal, (c) T_{re} increased to 39°C, or (d) a subject's sustained heart rate (HR) reached 90% of estimated maximum safe HR for age ($220 - \text{age in years}$). Clothed weight ($m_{f, \text{clothed}}$) was obtained immediately upon exiting the chamber. Subjects were seated in the preparation area while remaining dressed for approximately 2 min after weighing. If T_{re} had not declined below 39°C, the AR-5 was removed (if employed), boots removed, all garment zippers opened, and the subject rested. When T_{re} fell below 39°C, final seminude weight ($m_{f, \text{nude}}$) was measured, blood samples taken, and the subject medically cleared to leave.

PHYSIOLOGICAL INDICES

Physiological temperatures were analyzed as differences (e.g., $\Delta T_{re} = T_{re, final} - T_{re, initial}$) over an exposure period because within-subject initial temperatures varied between exposures. Mean weighted skin temperatures were calculated using the method of Ramanathan (reference 7):

$$[1] \quad T_{sk} = 0.3(T_{chest} + T_{arm}) + 0.2(T_{thigh} + T_{shin})$$

and the same relationship was used to calculate the mean weighted heat flux, HF_{mean} (W/m^2), by substituting HF_i for T_i where $i = chest, arm, thigh, and shin$. Skin convective heat losses were calculated from

$$[2] \quad Q_{conv} = (HF_{mean} \times SA \times 60)/1000 \quad kJ/min$$

Total sweat losses (SWL), including evaporation and dripping, was

$$[3] \quad SWL = m_{i, nude} - m_{f, nude} + \text{water consumed}$$

and the amount of sweat absorbed by the clothing was calculated by

$$[4] \quad \Delta GW = (m_{f, clothed} - m_{f, nude}) - (m_{i, clothed} - m_{i, nude})$$

Evaporated mass, m_{evap} , the difference between equations [3] and [4], was used to calculate evaporative heat losses, Q_{evap} , from

$$[5] \quad Q_{evap} = m_{evap} \times h_{fg}/t$$

where h_{fg} = heat of vaporization (2275 kJ/kg) and t = exposure duration. The sum of equations [2] and [5] represents the total heat loss, Q_{total} . The relationship between oxygen consumption and work rate is linear (reference 10) so that predicted VO_2 , can be based on body mass and ergometer workload (WL) from the equation

$$[6] \quad VO_2 = 5.8 \times m_{i, nude} + 151 + 10.1 \times WL \quad ml/min$$

from which metabolic heat production can be calculated.

STATISTICAL ANALYSIS

A goal in analyzing study data was to use each subject as their own control and eliminating between-subject variability. To accomplish this, each subject's physiological and physical (environmental and ensemble) data were analyzed from $t = 0$ to their minimum exposure time (t_{min}) in any of the tested configurations. This t_{min} data were also transformed by taking the ratio between a subject's given configuration and m75 results (e.g., $\Delta T_{re, h75} = \Delta T_{re, h75} / \Delta T_{re, m75}$). Certain data, however, were measured only before and after exposures (e.g., $\% \Delta PV$) and cannot be analyzed at t_{min} . Comparisons of this data were based on analysis of data transformed by dividing

the measured value by exposure duration. Cognitive response were analyzed by assessing correlation between percent correct answers, response times, and physiological parameters (ΔT_{re} , ΔT_{sk} , HF_{mean} , $T_{re} - T_{sk}$, and heat flux and temperature at seven skin sites). A one-factor (clothing configuration) analysis of variance was used to compare the physiological consequences of wearing each clothing ensemble. When the ANOVA detected significant differences among configurations, a Newman-Keuls post hoc test was used to identify those configurations which differed significantly from the others. Linear correlation analysis was used to assess relationships between variables. A nonparametric Kruskal-Wallis ANOVA was used to assess differences in the number of physical work periods at least half completed. Data are reported as mean values \pm standard errors of the mean. Differences were considered significant at the $\alpha = .05$ level.

RESULTS

Typical physiological temperature changes and blower flowrates are given in figure 5. Regional skin temperatures (T_{chest} , T_{arm} , T_{thigh} , T_{shin} , $T_{forehead}$), shown in figure 6, and T_{re} differed significantly between configurations during the preexposure rest period ($p < 0.05$). Consequently, variables were analyzed by comparing differences over the course of runs rather than final values. Figure 7 illustrates how mean ΔT_{re} differed between configurations over the course of runs while broadly falling into two groups (h75, h75n, and m75 versus h20, m20, and h75c). Figure 8 shows regional changes in skin temperatures and heat flux for grouped data. Positive heat flux indicates heat loss to the surroundings. In general, the order of skin temperatures measured 60 min into a given exposure were, from highest to lowest, chest and neck (34.0°C), arm (33.8°C), forehead (32.8°C), shin (32.6°C), and thigh (32.5°C).

The most significant factor in determining experimental results was ambient relative humidity (RH) while the combination of the Mk 1 and 20% RH proved to be the least stressful test condition. Table 4 and figures 9 and 10 show that m20 trials lasted significantly longer ($p < 0.01$) and were significantly less stressful (based on ΔT_{re} , ΔT_{sk} , ΔT_{chest} , ΔT_{arm} , ΔT_{thigh}) ($p < 0.05$) than 75% RH trials. Peak m20 HR, shown in figure 11, was also significantly lower during the first three exercise periods than h75 or h75n ($p < 0.05$). Furthermore, minimum HR measured during rest periods 1, 2, and 3 was significantly lower during m20 exposures than m75, h75, or h75n exposures (figure 12). Significantly greater exposure durations, smaller Δt_{re} , lower peak HR during the 2nd and 3rd exercise periods and lower minimum HR during rest periods 1, 2, and 3 were also observed in h20 trials compared with h75 or h75n trials ($p < 0.05$).

Table 4: Observed Subject Tolerance and Physiological Temperature Changes during Experimental Exposures

| | <i>Exposure Duration</i> | | ΔT_{re} | | $\Delta T_{re} \text{ hr}^{-1}$ | | ΔT_{sk} | | $\Delta T_{sk} \text{ hr}^{-1}$ | |
|----------------|--------------------------|------------|-----------------|------------|---------------------------------|------------|-----------------|------------|---------------------------------|------------|
| | <i>mean</i> | <i>SEM</i> | <i>mean</i> | <i>SEM</i> | <i>mean</i> | <i>SEM</i> | <i>mean</i> | <i>SEM</i> | <i>mean</i> | <i>SEM</i> |
| <i>m20</i> | 263 | 36.6 | 0.5 | 0.08 | 0.32 | 0.05 | 1.7 | 0.27 | 1.07 | 0.16 |
| <i>m75</i> | 129 | 10.6 | 1 | 0.15 | 0.64 | 0.09 | 2.8 | 0.13 | 1.76 | 0.11 |
| <i>h20</i> | 175 | 16.1 | 0.5 | 0.14 | 0.32 | 0.08 | 2.6 | 0.31 | 1.61 | 0.15 |
| <i>h75</i> | 105 | 9.5 | 1.2 | 0.16 | 0.72 | 0.09 | 3.9 | 0.26 | 2.45 | 0.16 |
| <i>h75n</i> | 106 | 7.4 | 1.1 | 0.14 | 0.65 | 0.05 | 3.2 | 0.18 | 1.97 | 0.14 |
| <i>h75c</i> | 160 | 26.9 | 0.9 | 0.17 | 0.56 | 0.15 | 3.1 | 0.29 | 1.97 | 0.28 |
| <i>overall</i> | 150 | 10.5 | 0.9 | 0.07 | 0.55 | 0.04 | 2.9 | 0.14 | 1.84 | 0.09 |

Ancillary cooling, however, reduced the effects of ambient RH. Exposure durations, ΔT_{re} , ΔT_{chest} , ΔT_{arm} , ΔT_{thigh} , peak exercise HR, and minimal resting HR observed during h75c exposures generally did not differ significantly from data obtained during 20% RH exposures. In addition, plateaus in minimum HR were achieved between rest periods 2 and 3 during m20, h20, and h75c exposures but not during m75, h75, or h75n exposures.

Employing an AR-5 had no effect on stress levels since h75 and h75n trials were of equal duration and equivalent temperature changes, peak HR, heat losses, and $\% \Delta PV$ were observed. Neck and head temperatures were also unaffected by the presence or absence on an AR-5. Figure 13 shows that no significant differences among configurations were observed for T_{nape} , T_{occ} , or T_{fore} despite h75n trials not employing a head/neck cowl.

Lack of the head/neck cowl contributed to differences in HAILSS ventilation. HAILSS inlet airflow was $87.6 - 92.0 \pm .6$ l/min during h20, h75, and h75c exposures but increased significantly to $125.0 \pm .9$ l/min during h75n exposures ($p < 0.01$). Other factors contributing to the study outcome include garment fit and comfort. Mk 1 garments were available in sufficient quantity to properly size each subject. This was not true with HAILSS as only two garments were available. Consequently, HAILSS was generally too large for the sample population and airflow about the skin was less than optimal.

Water consumption, heat losses, and lactic acid production generally did not differ significantly across configurations. Subjects consumed water at an average rate of $0.22 \pm .04$ kg/hr while losing $0.47 \pm .03$ kg/hr of total sweat and evaporating 40.8 ± 4.9 % of this sweat during exposures. Figure 14 shows how $\% \Delta PV$ dropped significantly during both h75 and h75n trials compared to the $\% \Delta PV$ rise observed during h75c trials ($p < 0.05$). These differences cannot be directly attributed to water consumption or sweating because $\% \Delta PV$ did not correlate with water consumption, sweat loss, or evaporative losses.

Calculated total heat loss averaged $13.59 \pm .89$ kJ/min (226 ± 14.8 W) among configurations with evaporative heat exchange accounting for 7.30 ± 0.83 kJ/min (121 ± 13.8 W). Regional heat fluxes, other than the chest, did not significantly differ as shown in figure 15. Subjects' chests gained significantly more heat under both Mk 1 conditions and h75n than under h75c which lost heat ($p < 0.05$). Predicted metabolic heat production was 12.7 kJ/min assuming that pedalling efficiency was limited to 10% because of the CBW ensembles. Stress levels were relatively high as indicated by blood lactic acid levels increasing by an average of 48.6 ± 7.7 % over the course of exposures.

Cognitive tests produced inconclusive results. No significant correlations between cognitive task performance and physiological state, environmental condition, or time were observed. Cognitive performance was also generally independent of ensemble worn.

Subjects experienced a general sense of being excessively hot in both the Mk 1 and HAILSS but found HAILSS to be relatively comfortable and noted that the AR-5 surprisingly aided in the level of comfort (see appendix). The most problematic complaints regarding HAILSS were skin abrasions due to the spacer material fraying and excess bulk. Integrating the AR-5 with HAILSS proved to be easy though the large AR-5 cowl extending over the shoulders undoubtedly added to the thermal insulation of the upper torso.

DISCUSSION

PHYSIOLOGY: The central question of this study, whether the HAILSS ensemble can outperform the Mk 1, can be answered affirmatively if ancillary cooling integral to HAILSS is provided. This conclusion, however, is based on study conditions intended to loosely reflect helicopter aircrew workloads. Estimated metabolic rates observed in this study are consistent with routine and combat pilot metabolic rates of 202 W (reference 4). It is worth noting, however, that loadmasters and other helicopter aircrew with more strenuous workloads will generate higher metabolic rates than those used in this study.

The relatively short exposure durations seen with m75, h75, and h75n are consistent with previous studies. McLellan, et al. (reference 6) found that tolerance times of individuals wearing CBW protection without cooling were less than 150 min even at light (238W) or moderate (385 W) workloads in 40°C, 50% RH conditions. Vallerand, et al. (reference 9) showed that cooling increased the capacity to tolerate hot, humid conditions (37°C, 50% RH) for up to 150 min. This study expands on these findings by demonstrating the importance of ambient relative humidity in predicting tolerance times in CBW protective clothing.

Physiological strain produced by these conditions was demonstrably less at 20% RH than at 75% RH based on exposure durations and ΔT_{re} for both Mk 1 and HAILSS. Active cooling, however, eliminated RH-based differences in HAILSS. Cross-garment comparisons suggests that actively cooling the baseline HAILSS design, even in 75% RH, can reduce thermal strain to levels approaching those currently experienced in the Mk 1 at 20% RH. Improved heat tolerance came despite lower than desired airflow rates and a moderate inlet air temperature. Generating greater airflow and further reducing inlet air temperatures probably would further enhance heat tolerance

for HAILSS users and may allow them to experience less heat strain than current users of the Mk 1.

Neither the current Mk 1 or HAILSS, however, were capable of removing sufficient metabolic heat to maintain $\Delta T_{re}/t$ below 0.25°C/hr under the study conditions. Maintaining homeostasis should have been achievable given that heat extraction rates exceeded estimated heat production by at least 7%. Physiological measures of stress (T_{re} , HR, blood lactic acid), however, all suggest increasing levels of heat storage during exposures. In addition, observed $\Delta T_{re}/t$ was 120% greater than the target $\Delta T_{re}/t$. Clearly, heat removal demands were unmet by either garment given the rising stress levels. Apparent discrepancies between estimated heat production and removal are probably due to underestimating actual metabolic rates and physiological responses to the microenvironment.

Circulatory demands imposed by heavy exercise in a hot environment probably best explains this difference between theoretical heat losses necessary for homeostasis and actual heat losses. Equivalent HAILSS and Mk 1 sweat rates and heat losses despite significantly different physiological responses also suggest that circulatory stresses may be the dominant determinant for observed physiologic responses. Vigorous exercise in the heat imposes a contradictory demand on the cardiovascular system. Active muscles require enhanced blood flow to supply needed oxygen and metabolites while thermoregulation requires enhanced peripheral blood flow to dissipate excess metabolic heat to the environment. Sweating without adequate fluid replacement exacerbates this problem by steadily reducing plasma volume. Circulatory adjustments made to maintain central arterial pressure under these multiple demands include diminished visceral blood flow. Peripheral blood flow will ultimately be compromised if circulatory demands are sufficiently great. Consequently, less heat is transported to the skin surface, less fluid is available for sweat production, and both convective and evaporative heat loss declines.

Wearing semipermeable or impermeable clothing further reduce heat and water vapor exchange with the surroundings. Clothing material acts as a thermal insulator and impairs air exchange between the ambient environment and the microclimate existing between the skin and inner clothing surface. Reduced air exchange diminishes both convective and evaporative heat exchange. Loosely worn and permeable clothing, like the Mk 1, or artificial ventilation, like that used by HAILSS, improves the situation but may not be sufficient to totally ameliorate these effects. Passing cool air through the clothing microenvironment, as in h75c exposures, cools skin surfaces which increases temperature gradients and heat transfer from body core to skin to microenvironment. Enhanced cooling of warm blood passing through cool skin augments increased conductive heat transfer through body tissues by greater convective heat transfer from perfused warmer central tissues. In the context of the current study, heat transfer to the microenvironment seems to be a rate-limiting function but shifting stored heat from the viscera to the skin probably reduces physiological strain.

The capacity to tolerate mission-related workloads in these environments was reflected in the number of exercise periods at least half completed. This measure differed somewhat from exposure duration in that an exposure could terminate during one of three situations: (a) a rest period; (b) in the midst of an exercise period; or (c) at the end of an exercise period. Depending

on when trial terminations occurred, a greater or lesser number of exercise periods may have been completed. Presumably, an increasingly exhausted subject would be less inclined to begin, let alone complete, evermore exercise bouts than an energetic subject. Consequently, nearly equivalent exposure durations may reflect differing numbers of complete or nearly complete exercise periods which probably reflect an individual's physical capacity. The m20 configuration was the least stressful on this basis which conforms with previously discussed measures. The h20 and h75c configurations, though substantially more stressful than the m20, appear less stressful than either the m75, h75, or h75n. Minimizing heat stress by using HAILSS appears to increase the capacity to tolerate mission-related workloads in high heat environments based on this criteria.

One question which this study addressed was whether wearing a protective ventilated hood like the AR-5 adversely affected an individual's thermal balance or whether it was beneficial. Employing the AR-5 as designed for field use, i.e., inlet air was neither cooled nor dehumidified, nearly all measures of thermal stress were essentially identical between h75 and h75n trials. This strongly suggests that the AR-5 hood had little impact on overall heat exchange. Even head and neck temperatures were unaffected by the presence or absence of the AR-5. One advantage of AR-5 use, however, was increased subjective comfort among test subjects who generally noted less subjective heat stress when the AR-5 was employed (see appendix).

EQUIPMENT: It is worth noting that ventilation rates varied widely during this study. Three factors, HAILSS fit, blower supply voltage, and ventilation hose patency appeared to play the greatest roles in determining flow rates. Garment fit did not appear to significantly affect airflow back pressure but ventilation hoses on improperly fitting HAILSS ensembles tended to kink. Hose kinking was remedied in this study by having observers vigilantly readjust ventilation hoses whenever ventilation rates noticeably declined but this could be a problem during field use. Improper fit also creates "voids" within the garment, i.e., areas where there is a larger than normal space between the spacer material inner surface and the outer surface of the underwear. These voids provide low pressure ventilation pathways, causing air to move preferentially through these spaces and avoid more tightly fitting areas. This may reduce cooling efficiency by isolating large surfaces from ventilation.

The SAB-87 blower depends on the supply voltage provided by an electrical source to maintain a constant airflow rate. Originally designed for drawing power from five standard "D" cell batteries, SAB-87 units were initially employed this way. It was soon discovered, however, that SAB-87 airflow rates dropped precipitously as batteries weakened. Use of a DC power supply eliminated this problem during this study but replacement batteries will be needed during extended field use of the SAB-87 with HAILSS. Perhaps the most intriguing puzzle of this study was a gradual decline between runs in airflow through the first HAILSS ensemble employed by subjects. This garment was used exclusively until the diminished airflow rate compelled investigators to begin using a second ensemble. It appears the spacer material used in the ventilation inlet tube was being flattened over time, thereby reducing tube patency, increasing back pressure on the blower, and restricting airflow.

Results from this study suggest a number of possible HAILSS improvements. Blower flow rates varied from 75-133 l/min and was somewhat less than prestudy measurements of 128-157 l/min. Increasing blower output would increase both convective and evaporative heat transfer and might increase subject comfort. Other potential means of increasing flow rates include replacing existing outlet valves with lower resistance valves and using larger diameter inlet tubing.

Scrapping and rubbing caused minor abrasions on at least two subjects. These injuries resulted from stiff spacer material slightly unraveling at seams bunching of cloth behind subjects' knees. Better seam manufacturing and proper fitting should prevent this from happening in the future.

Developing improved cooling systems and integrated clothing ensembles will depend on acquiring greater understanding of physiological cooling mechanisms. Among the questions to be answered are: 1) Do garment ventilatory patterns (e.g., periphery versus torso, shin versus thigh) result in differences between comfort and efficient heat extraction?; 2) What are optimal garment airflow rates and do they differ between body regions?; 3) Does the shift of heat from the body core to the skin affect work capacity and physiological strain more than heat removal?; and 4) Does subjective comfort relate to physiological strain? Significant strides in cooling methods may occur when these questions can be answered.

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CONCLUSIONS

Increasing heat removal by improved cooling methods allows HAILSS to exceed performance levels seen in the Mk 1. Ancillary cooling brought the level of heat strain experienced in the HAILSS assemble at 75% RH to roughly that of Mk 1 or HAILSS at 20% RH.

HAILSS or Mk 1 without ancillary cooling was demonstrably more stressful to wear at 75% RH than at 20% RH. Operational mission performance would likely degrade at this higher RH without active cooling.

Ambient relative humidity significantly affects heat removal even in totally encapsulated protective clothing ensembles.

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Figure 1: HAILSS baseline ensemble configured for present study. Note the SAB-87 blower attached for preexposure ventilation. The large “patch” on the left elbow is instrumentation for measuring exhaust air conditions (temperature, relative humidity). The large bundle of wires held by the subject are connected to various bioinstrumentation sensors placed under the outer garment.



Figure 2: USN A/P22P-9(V) (Mk 1) ensemble configured for present study. The large box on the left wrist is bioinstrumentation transducer. The large bundle of wires held by the subject are connected to various bioinstrumentation sensors placed under the outer garment. No forced ventilation is provided with this ensemble.

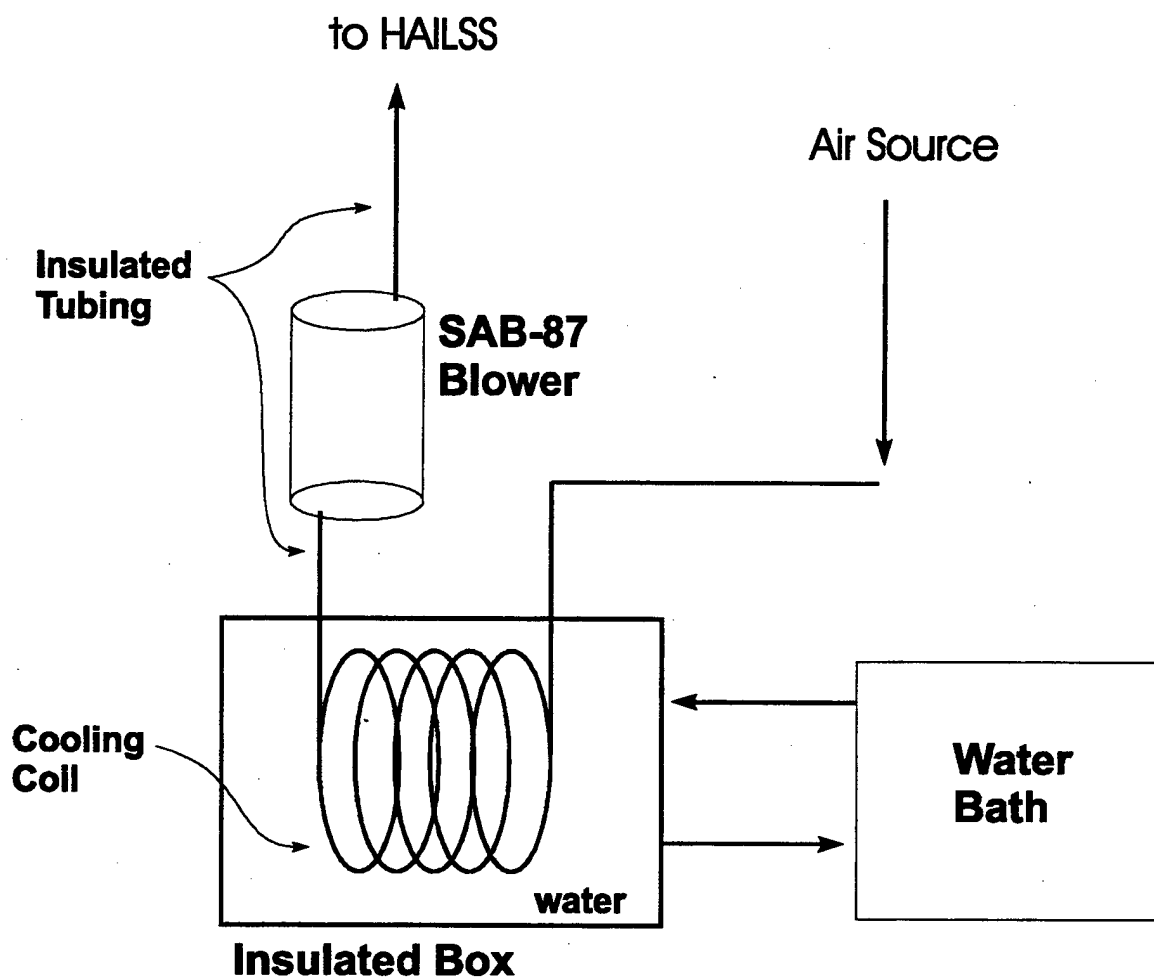
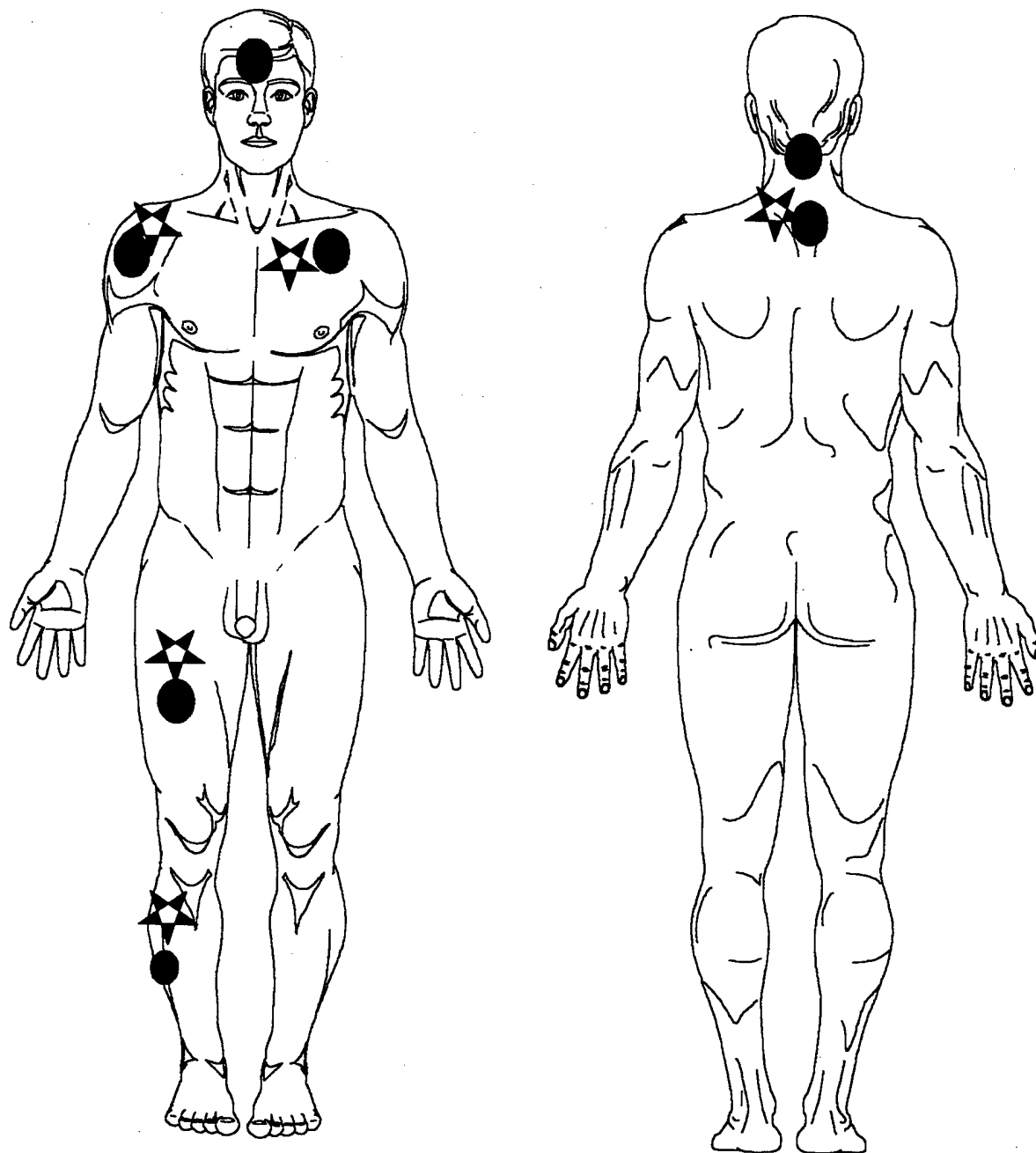


Figure 3: Schematic drawing of the cooling sytem used with during h75c exposures. Air was delivered from an oil-free compressor passed through the cooling coil located in a constant temperature bath and existed into the HAILSS garment via the SAB-87 blower. Water temperature was maintained by the external controlled temperature water bath.



● - Thermocouple

☆ - Heat Flux Transducer

Figure 4: Location of thermocouples and heat flux transducers affixed to the skin to measure surface temperatures and heat transfer with surroundings.

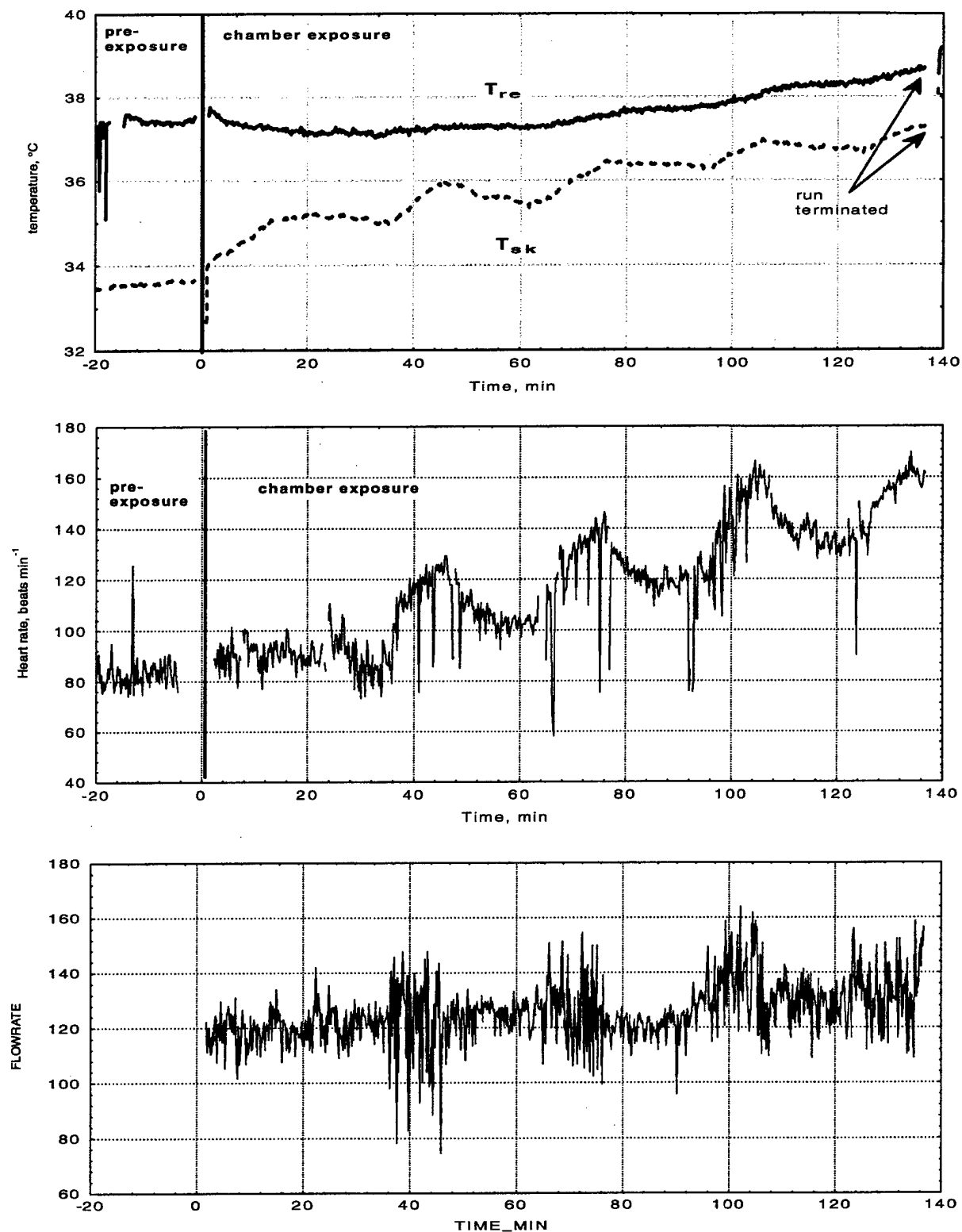


Figure 5: Heart rate, rectal and mean skin temperature data from a typical subject's exposure. The subject in this instance was wearing HAILSS in 75% RH without cooling. Blower flowrate data are given in the lower graph.

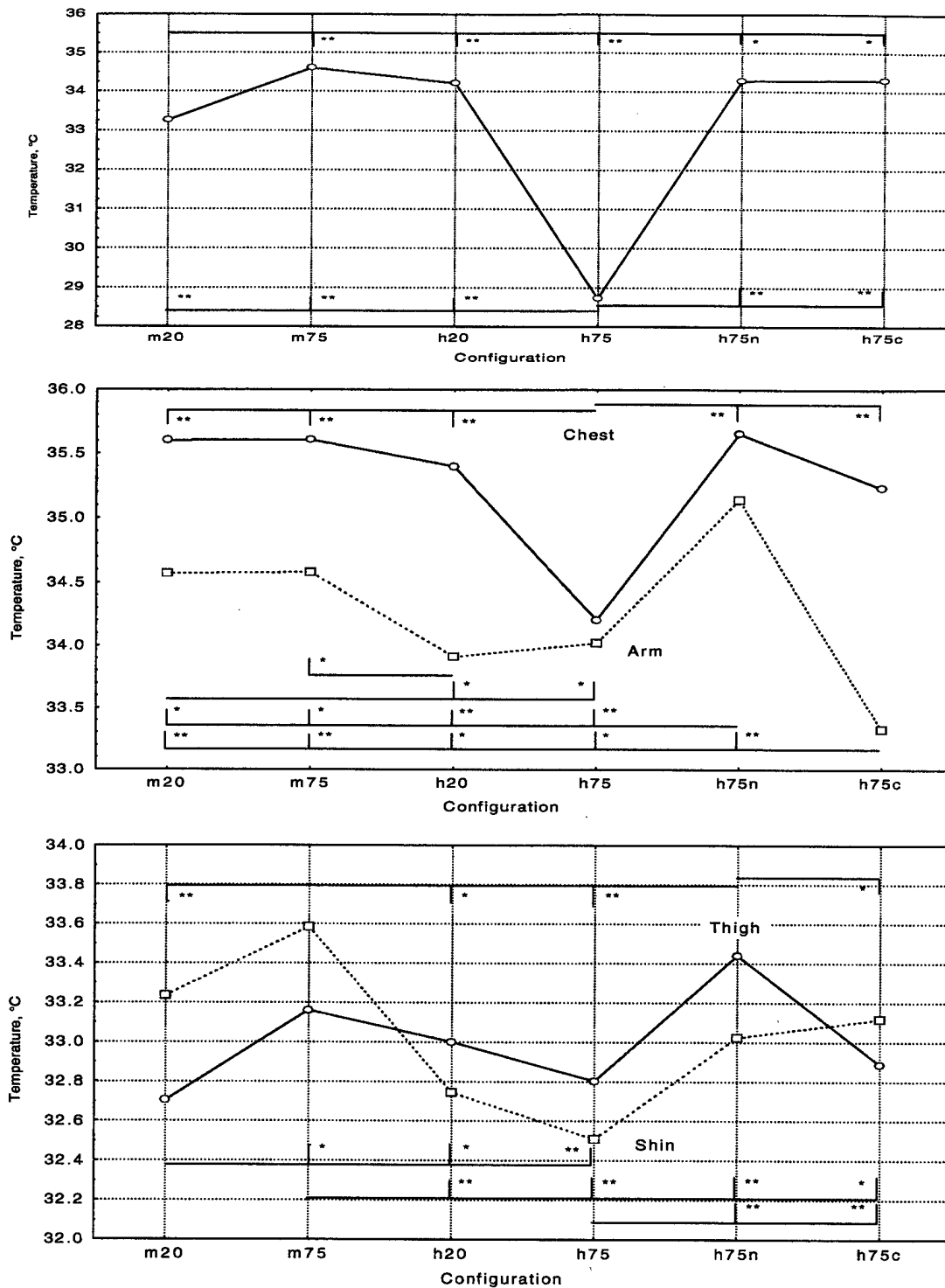


Figure 6: Regional skin temperatures during preexposure rest period. Figures represent forehead (top), chest and arm (middle), and thigh and shin (bottom) temperatures. Significant differences are indicated by * < 0.05 , ** < 0.01 .

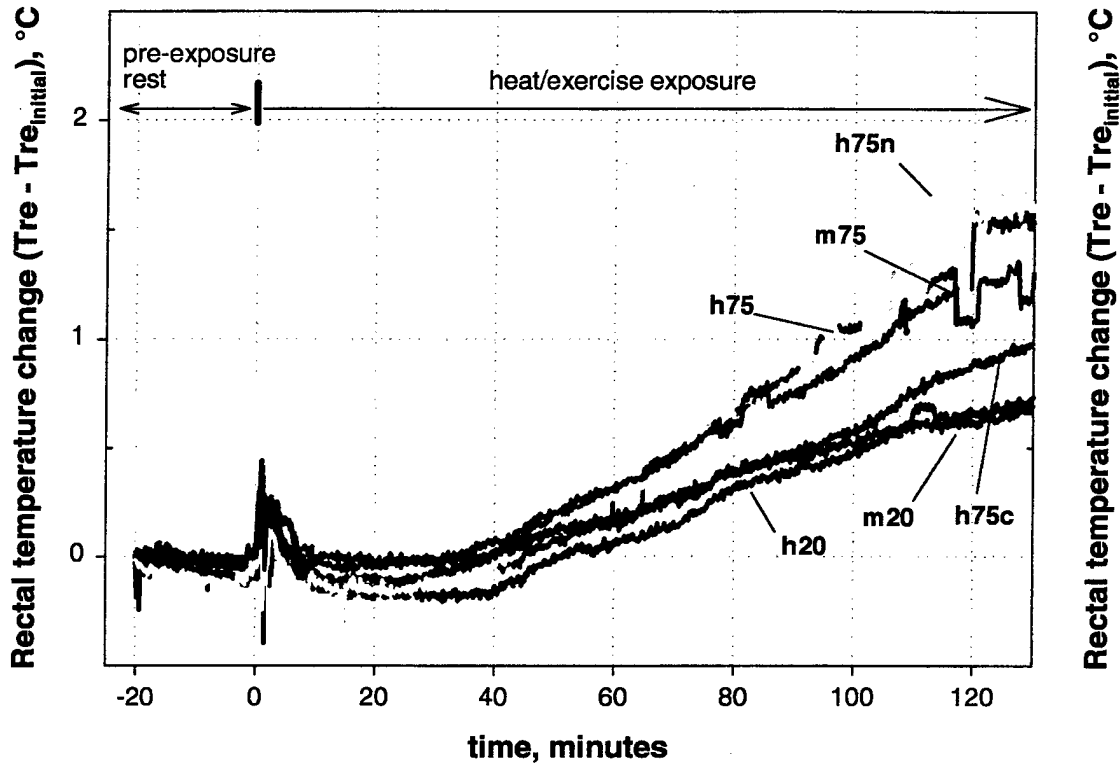


Figure 7: Mean rectal temperature (T_{re}) changes for each experimental clothing configuration as a function of exposure time. Changes in rectal temperatures were defined as T_{re} at time t minus T_{re} at the start of the preexposure rest period ($t = -20$). All configurations except m20 began with $n = 7$ ($n=5$ with m20). The number of subjects represented by the curves begin to drop below the starting n after roughly 100 min and accounts for the graph discontinuities.

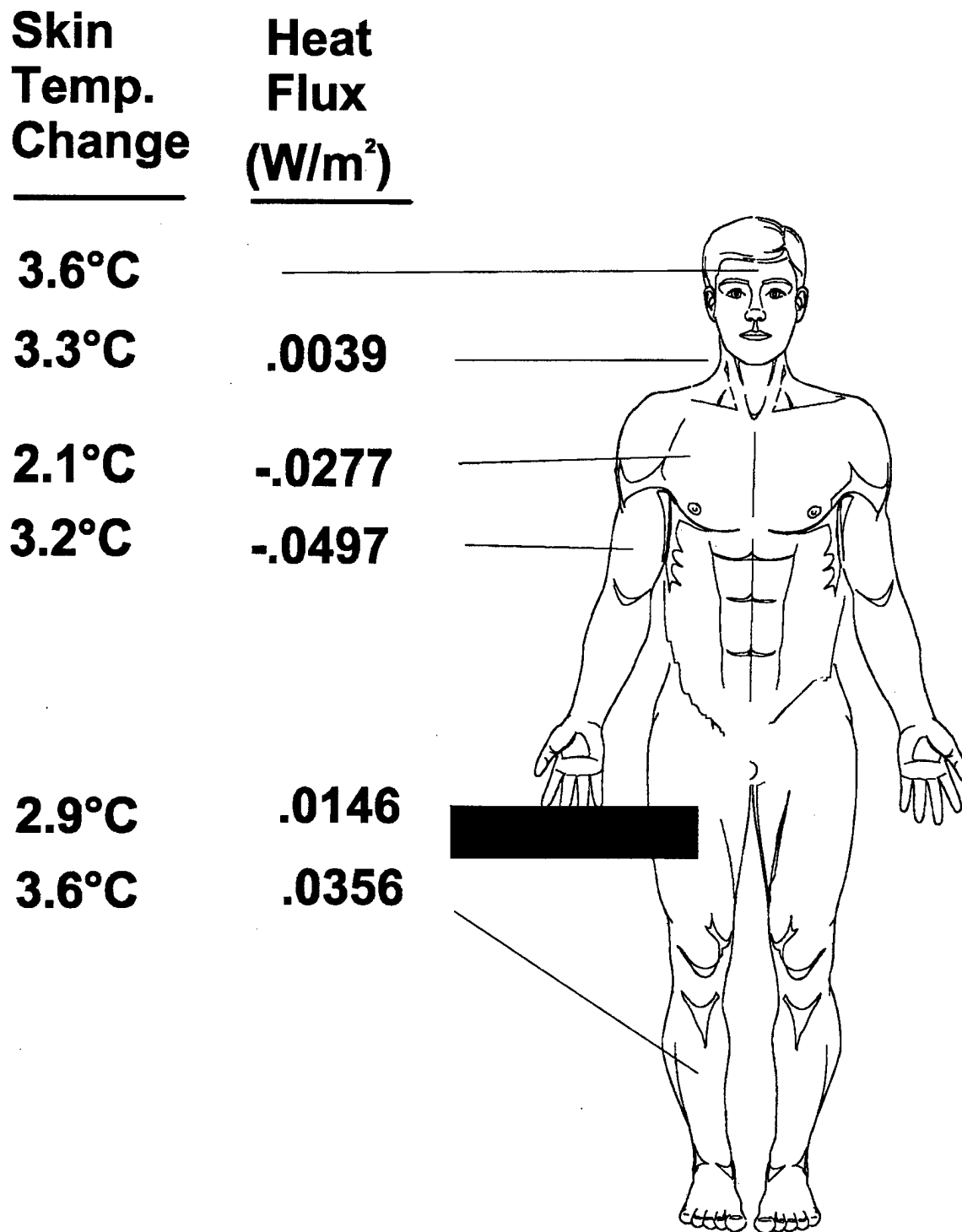


Figure 8: Mean changes in skin surface heat flux and temperature occurring 60 min into exposures. Results were pooled among configurations because differences were generally not significant. Positive heat flux indicates the body is losing heat to the surroundings.

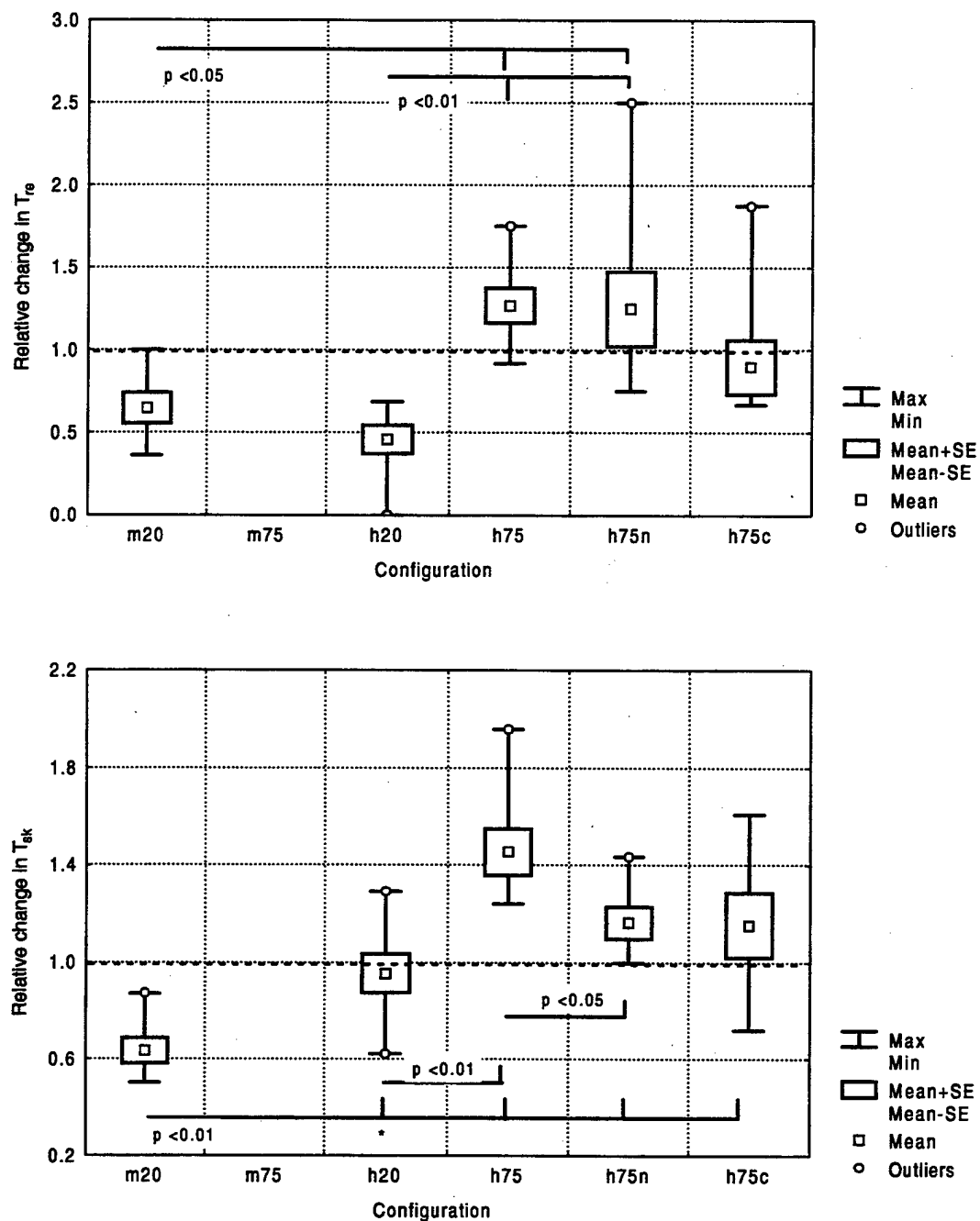


Figure 9: Changes in rectal (top) and mean skin (bottom) temperatures as a function of clothing configuration relative to individual m75 responses. Significant differences are as indicated on each graph with * = $p < 0.05$.

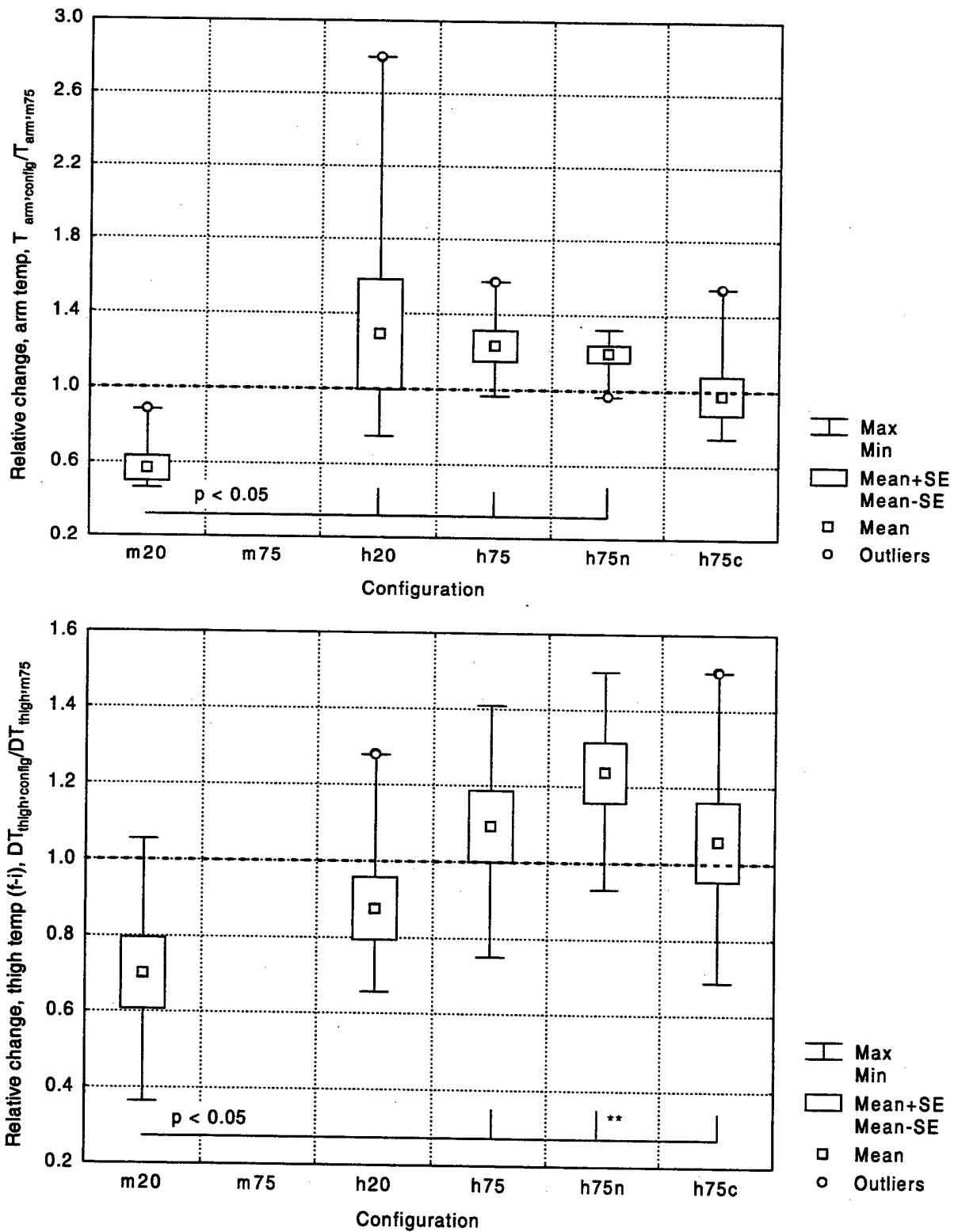


Figure 10: Changes in arm (top) and thigh (bottom) temperatures as a function of clothing configuration relative to individual m75 responses. Significant differences are as indicated on each graph with $** = p < 0.01$.

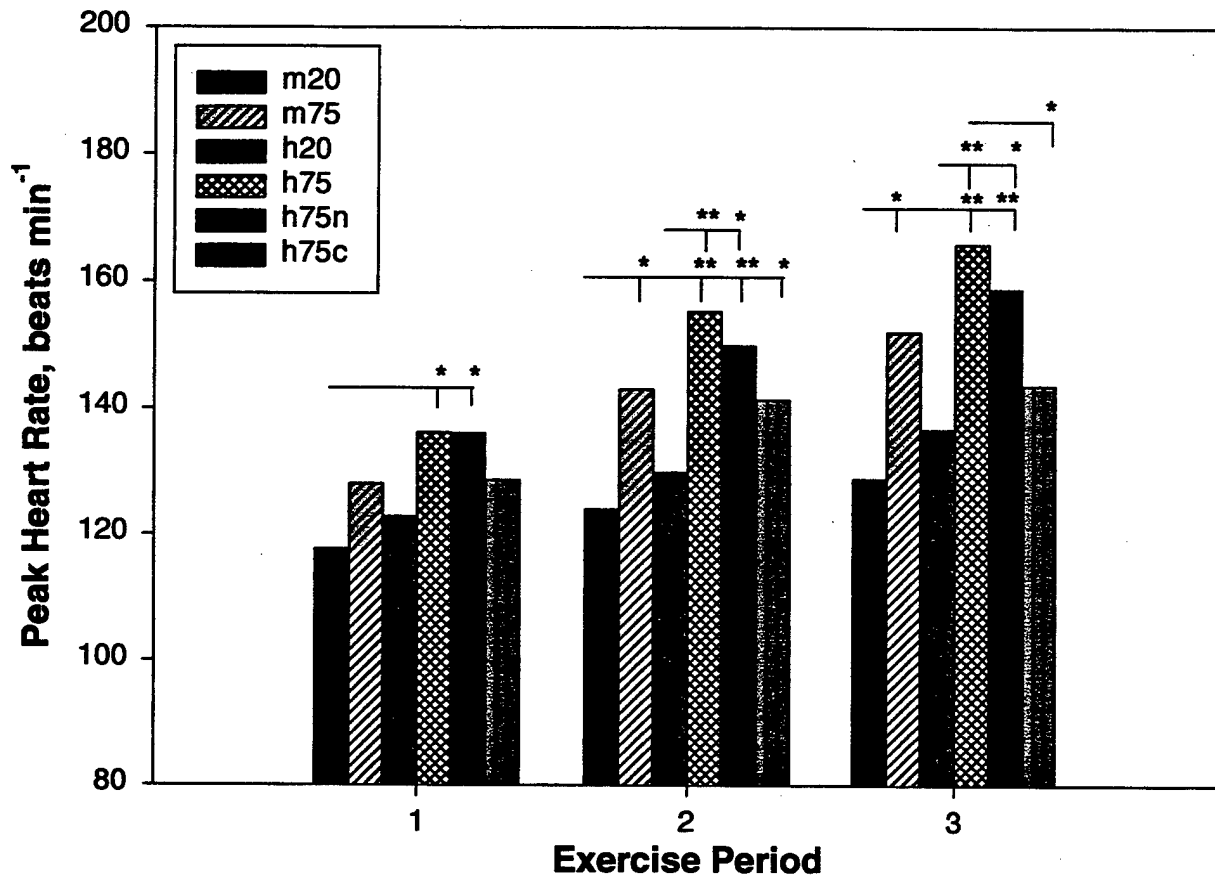


Figure 11: Mean peak heart rate during the first three exercise periods of each exposure by configuration. Steadily increasing heart rates strongly suggest increasing physical stress levels. Significant differences are indicated on each graph as * = $p < 0.05$, ** = $p < 0.01$.

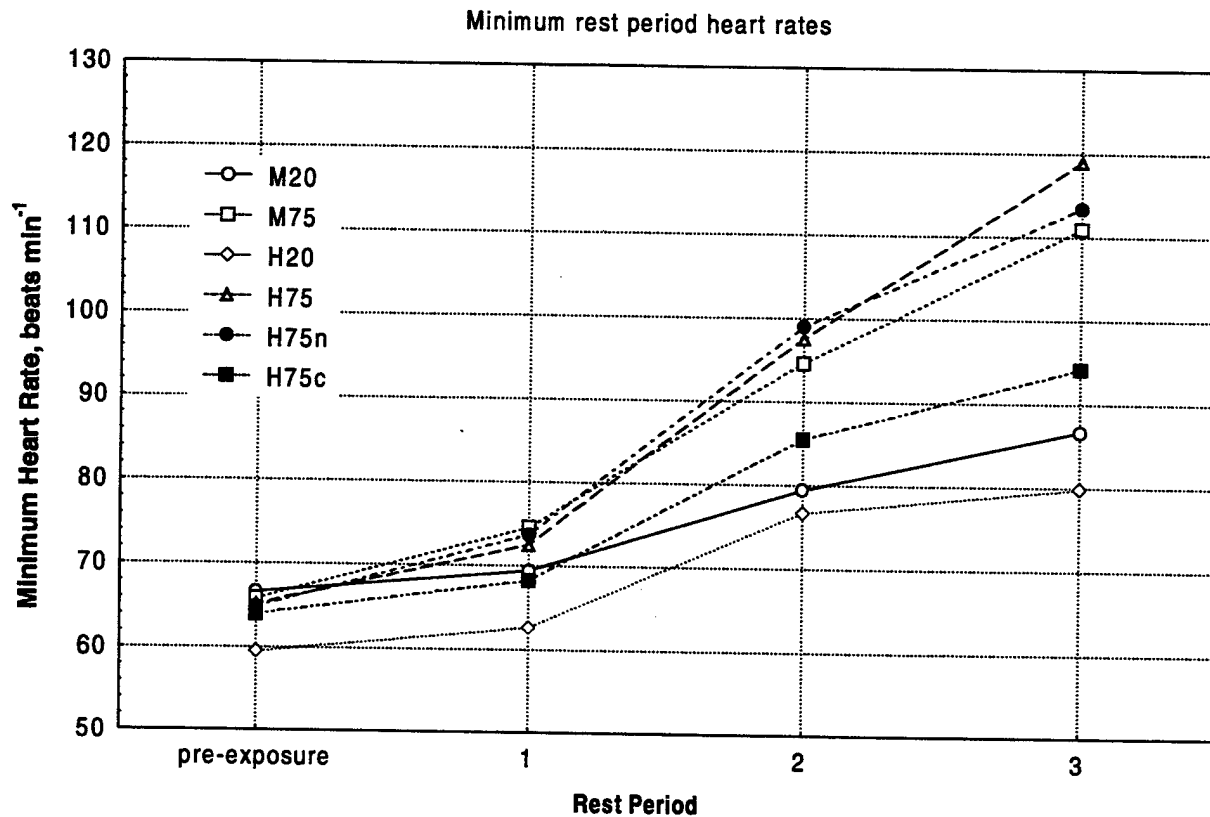


Figure 12: Minimum heart rates observed during the preexposure rest period and the first three exposure rest periods. Preexposure and rest period 1 minimum heart rates did not differ significantly between configurations. Minimum heart rates increased significantly with each successive rest period for m75, h75, and h75c, but only between rest periods 1 and 2 for m20, h20, and h75c ($p < 0.05$).

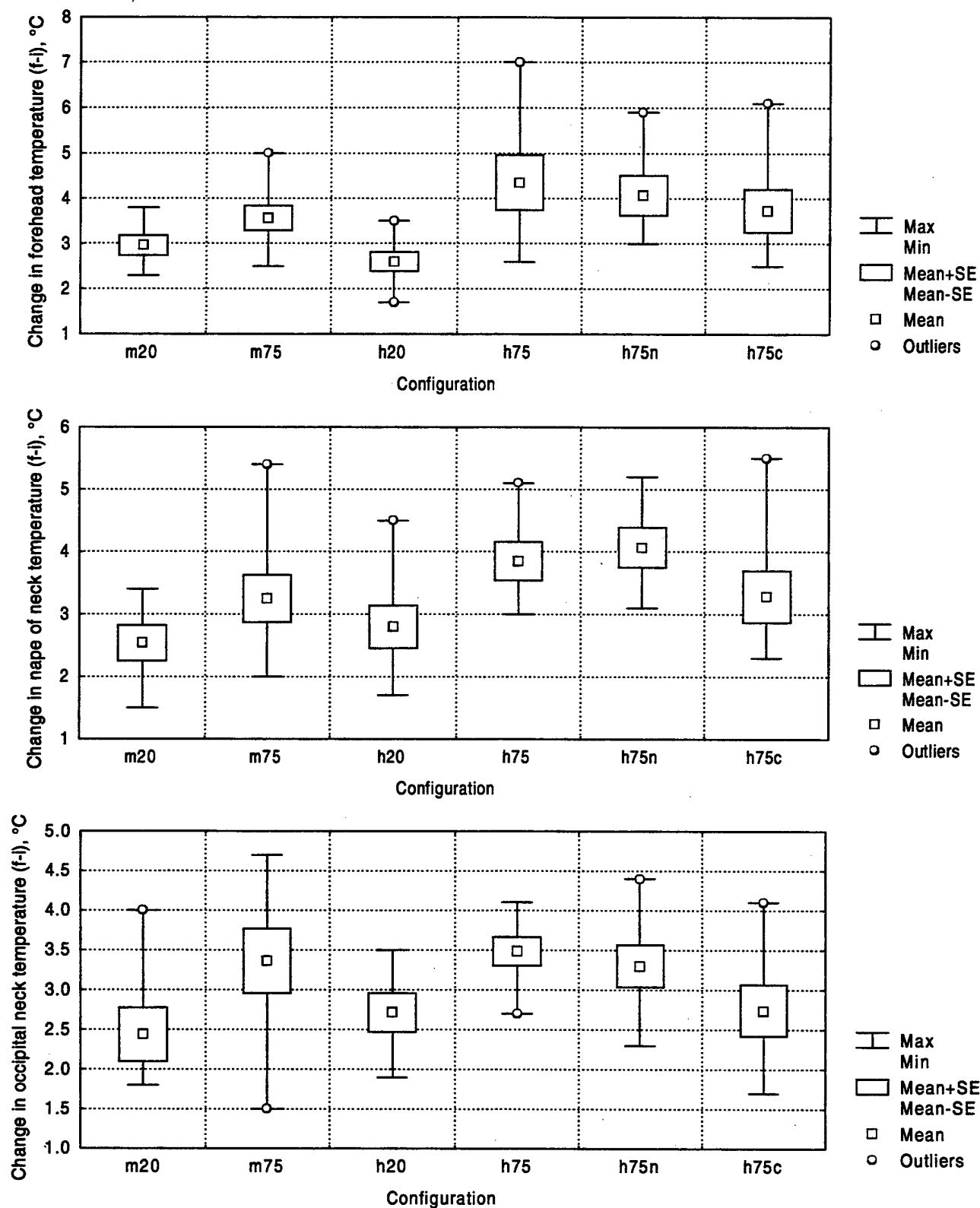


Figure 13: Mean changes in forehead (top), nape of neck (middle), and occipital neck (bottom) temperatures by configuration.

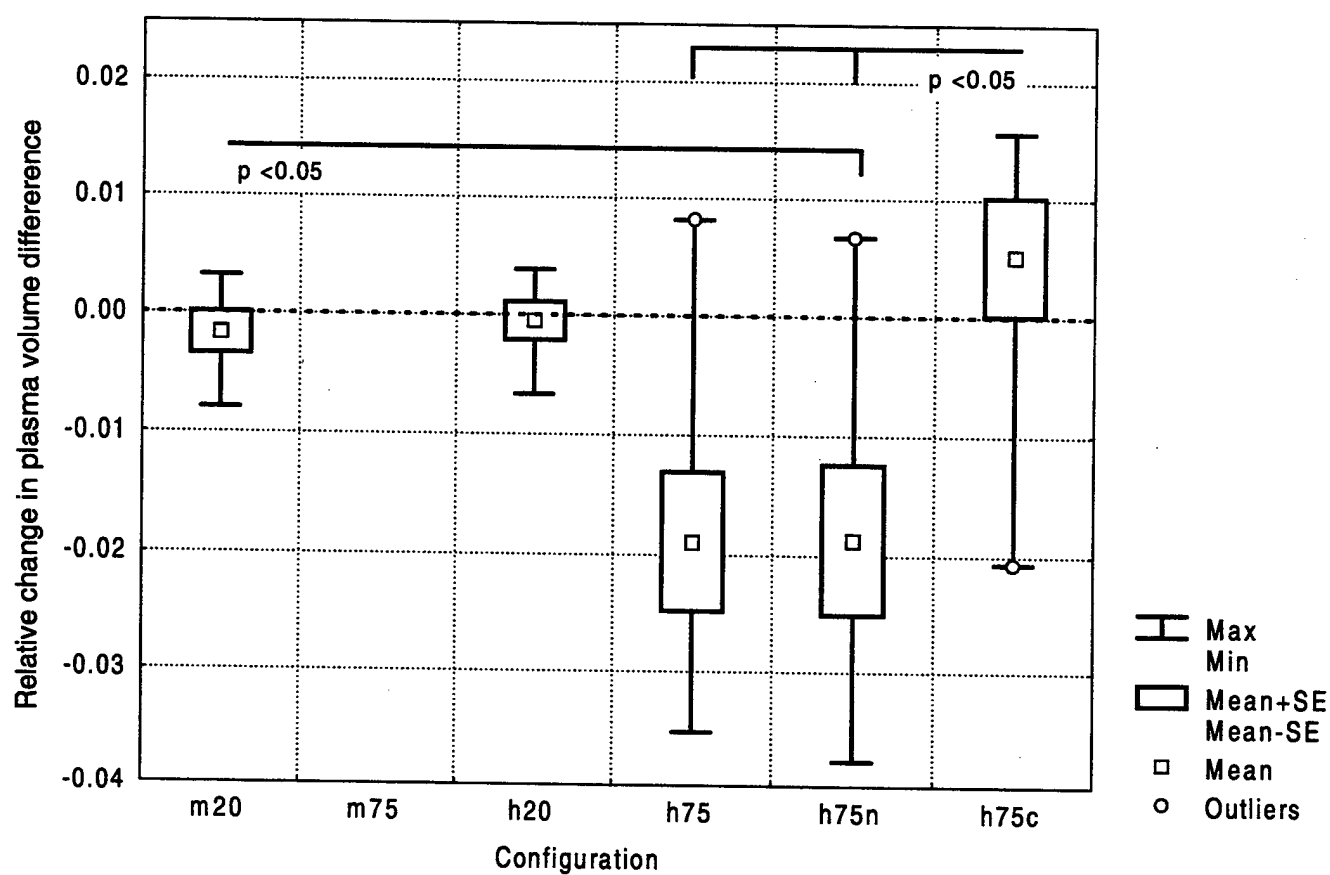


Figure 14: Percent change in plasma volume by configuration relative to m75 results. Significant differences between configurations are indicated by the horizontal lines.

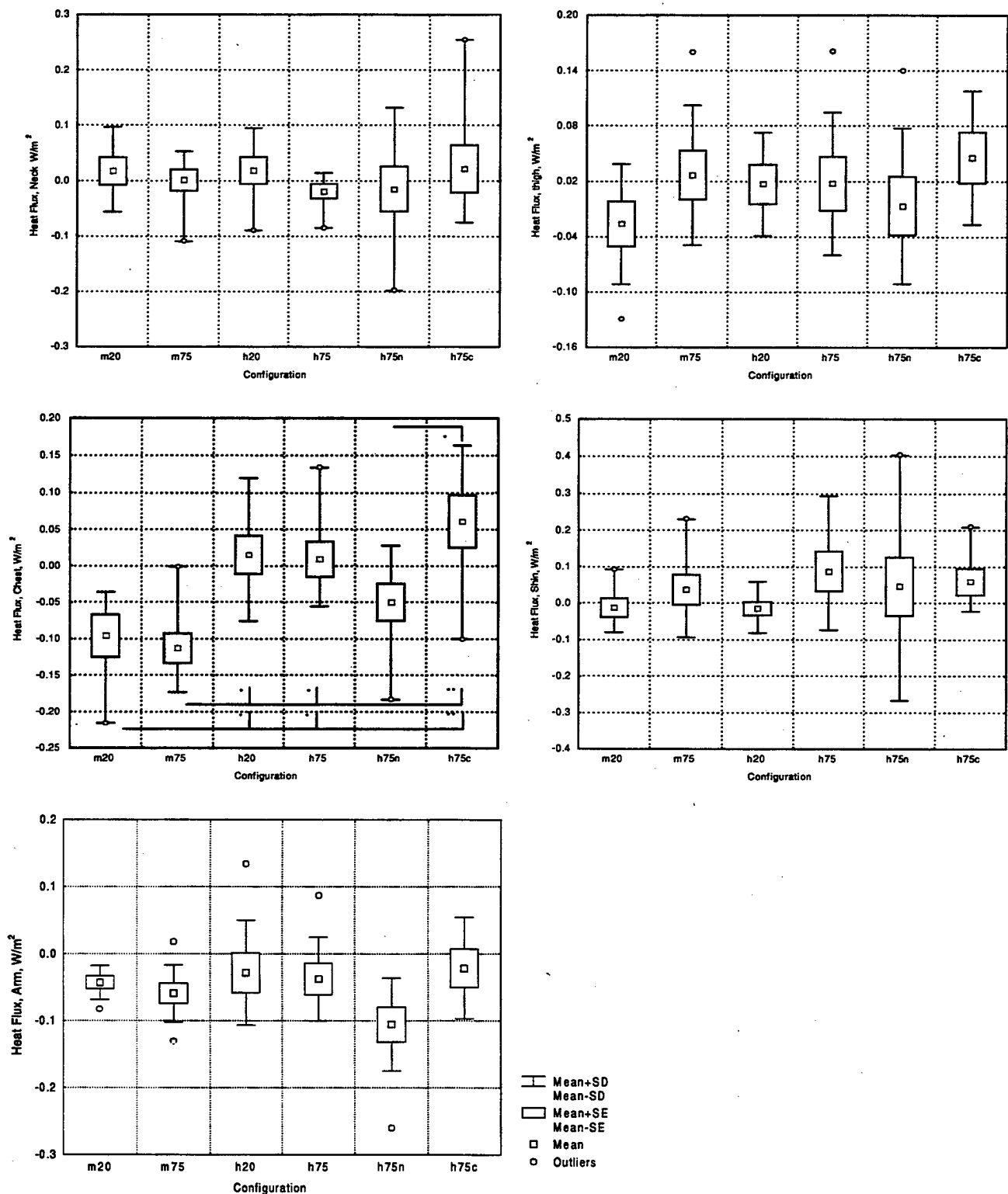


Figure 15: Heat flux measured at various body regions by configuration: neck (top left), chest (middle left), arm (bottom left), thigh (top right), and shin (middle right). No significant differences between configurations were observed except at the chest. Positive values indicate heat flowing out from the body.

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APPENDIX
SUBJECT POSTEXPOSURE COMMENTS

| Subject | Date | Configuration | | | | Subject Comments |
|----------------------|-----------|---------------|---------|-----------|--------------------|---|
| | | Garment | AR 5 | RH (%) | Inlet Air Temp. | |
| Mk 1 - 20% RH | | | | | | |
| R.N. #3 | 15 Dec 97 | Mk 1 | Y | 20 | none | a) Mk 1 lighter and less cumbersome b) Both suits equally cool |
| L.M. #4 | 25 Feb 98 | Mk 1 | Y | 20 | none | a) Ended run because she was "sleepy tired" and had trouble focusing on tasks b) Easier when pedalling c) She felt she had trouble remembering what to do during cog task periods 1 and 2 d) Comfortable during run but felt warm with periods of increasing heat e) More comfortable than HAILSS because HAILSS was stiffer f) Felt a "flush" feeling of heat after each time pedalling stopped g) Undershirt and thighs moist, otherwise dry |
| R.A. #4 | 18 Mar 98 | Mk 1 | Y | 20 | none | No recorded comments |
| M.K. | 19 Mar 98 | Mk 1 | Y | 20 | none | a) Feels better than last run (h75n) b) Ears hurt from earcup pressure c) Felt much cooler than last run d) Legs felt cooler (in h75n only shins felt cool) e) Breathing air felt cooler f) Could have continued past termination g) Felt distracted toward end (visual distractions in room, lost in thoughts) h) Perceived was in chamber approx. 1 hr less than actual time i) Made conscious effort to drink more in beginning of run |
| A.W. #6 | 27 Mar 98 | Mk 1 | Y | 20 | none | a) Terminated due to mask discomfort – no tape or moleskin b) Distracted from last two cognitive tasks because of minor pains c) Easiest of all conditions d) Cooler when lifted off suit e) Only sweated in last two rides around face f) No finger tingling g) Not too thirsty h) Underwear dry i) Functioned better in Mk 1 – fit better, cooler, likes Mk 1 over HAILSS j) Face and shoulder pain |
| Mk 1 - 75% RH | | | | | | |
| R.N. #4 | 18 Dec 97 | Mk 1 | Y | 75 | none | a) Hot but not baking hot "sweaty hot": HAILSS felt baking hot Mk 1 somewhat better b) Mk 1 sticks during pedalling when you |

| | | | | | | |
|---------|-----------|------|---|----|------|--|
| | | | | | | <p>sweat "doesn't slide"</p> <p>c) Relatively comfortable but beginning to get tired toward end of run</p> |
| M.L. #1 | 21 Jan 98 | Mk 1 | Y | 75 | none | <p>a) Respirator mask fit poorly at chin</p> <p>b) Felt friction at ball of feet when pedalling - "burning"</p> <p>c) Fatigued when asked for new battery</p> <p>d) Felt a "chill down the spine" just prior to run termination - thinking of ending run before beginning of next work cycle</p> |
| V.M. #4 | 5 Feb 98 | Mk 1 | Y | 75 | none | <p>a) Sweaty, generally tired</p> <p>b) Chaffing behind right knee</p> <p>c) Didn't feel like working as hard as in 75% RH, didn't feel exhausted, heart not pounding</p> <p>d) 1st time felt pulling under arm (about arm pit)</p> <p>e) AR5 mask limits field of view</p> <p>f) Less water came out of mask than in previous runs</p> <p>g) When undressing, hose was in front - didn't bunch up initially</p> <p>h) Stretch material connecting mesh had red (blood?) stain (photos taken)</p> <p>i) Discomfort behind knees just like last run (HAILSS, AR5, 75% RH, 24°C inlet air)</p> |
| R.A. #1 | 23 Feb 98 | Mk 1 | Y | 75 | none | <p>a) Subject feels fine</p> <p>b) Feels body used to heat exposures from being stationed in Guam and many helicopter flights</p> <p>c) Has worn CWU-60/P during helicopter flights</p> <p>d) Has worn AR5 during operations but not with rest of chemical defense ensemble</p> <p>e) Blood pressure cuff felt tight</p> <p>f) Felt comfortable throughout run</p> |
| L.M. #6 | 13 Mar 98 | Mk 1 | Y | 75 | none | <p>a) Really hot</p> <p>b) Comfortable but HOT</p> <p>c) More comfortable than HAILSS</p> |
| A.W. #4 | 23 Mar 98 | Mk 1 | Y | 75 | none | <p>a) Had problems with either breathing or lightheadedness during cognitive tasks - okay during pedalling</p> <p>b) (a) first noticed during 2nd to last cognitive task and got progressively worse</p> <p>c) Would have terminated run if investigator had not</p> <p>d) This suit fit better but had much greater problems with breathing and lightheadedness</p> <p>e) Couldn't localize source of breathing problem</p> <p>f) Finger tips "tingled" during cognitive tasks</p> <p>g) Big toes momentarily "tingled" during pedalling</p> |

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|------------------------|-----------|--------|---|----|----|--|
| | | | | | | <ul style="list-style-type: none"> h) "Tingling" was distracting i) Didn't feel like sweating during cool down but restarted about 7 min into pedalling, slow breathing until then j) Rectal probes came out part way sometime during test |
| M.K. #3 | 23 Mar 98 | Mk 1 | Y | 75 | 35 | <ul style="list-style-type: none"> a) Ears hurt from helmet pressure b) Experienced back pressure from mask during exhalation - more noticeable as you get increasingly tired c) Just as hot as 1st run (h75n) d) Hottest initial sensation was 1st run (h75n) this run was least e) Got shivers toward end f) Mask makes this most uncomfortable g) Mk 1 felt you could get "cooler" than in HAILSS by moving about - could sense breeze - not true in HAILSS h) Mk 1 mobility better i) Getting sick of cognitive tests - Baddeley (reasoning) is worst j) Smelled ammonia in mask |
| HAILSS - 20% RH | | | | | | |
| L.M. #2 | 20 Jan 98 | HAILSS | Y | 20 | 35 | <ul style="list-style-type: none"> a) Suit feels bigger at neck and smaller (pushing down on head) than first run b) No subjective difference in torso temp between runs #1 and #2 c) Very bored during run d) Breathing air was very dry (lips very dry very quickly) e) Respirator mask seal failed once sweating began f) Left eye closed during cognitive testing because hair directed sweat into eye g) Run ended because subject "tired and aggravated" but not fatigued h) Chin and nose hurt from movement of mask and sweating |
| V.M. #3 | 30 Jan 98 | HAILSS | Y | 20 | 35 | <ul style="list-style-type: none"> a) Wasn't as fatiguing as last run (HAILSS, AR5, 75% RH) while pedalling or immediately after pedalling b) Air entering suit noticeably drier c) Felt nausea on occasion (randomly) - overwhelming sense of fatigue and exhaustion d) Last two cognitive tests had problems with sweat dripping in eyes e) Stopped because of exhaustion f) Mask fit better but not a tight seal - had to jut out jaw to actually seal mask g) Suit was "relatively" comfortable - no particular spot was uncomfortable |
| R.N. #6 | 3 Feb 98 | HAILSS | Y | 20 | 35 | <ul style="list-style-type: none"> a) Sweaty, generally tired b) Chaffing behind right knee c) Didn't feel like working as hard as in 75% RH, didn't feel exhausted, heart not pounding |

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| | | | | | | <ul style="list-style-type: none"> d) 1st time felt pulling under arm (about arm pit) e) AR5 mask limits field of view f) Less water came out of mask than in previous runs g) When undressing, hose was in front - didn't bunch up initially h) Stretch material connecting mesh had red (blood?) stain (photos taken) i) Discomfort behind knees just like last run (HAILSS, AR5, 75% RH, 24°C inlet air) |
| M.L. #5 | 17 Feb 98 | HAILSS | Y | 20 | 35 | <ul style="list-style-type: none"> a) Stopped run because coccyx pain from chaffing of rectal probe, left ear pain due to helmet pressure, and bridge of nose pain due to respirator mask pressure b) Moleskin placed at coccyx prior to run rubbed off during run c) Felt similar to previous run (HAILSS, AR5, 75% RH, 24°C inlet air) d) Could have lasted at least one more exercise period except for pain e) Felt air flow at small of back f) No noticeable pressure points on suit |
| A.W. #3 | 19 Mar 98 | HAILSS | Y | 20 | 35 | <ul style="list-style-type: none"> a) Lightheaded after last pedalling but improved during last cognitive task b) Binding on top of knees during 2nd pedalling - one of the Tcs popped off c) Neck got sore during 2nd cognitive task because breathing tube forced head into awkward position d) "Didn't feel nearly as hot as either time before" (previous runs - h75, h75n) e) Heat didn't seem to be a problem until end when lightheaded f) Recovery seems faster than 1st time wore AR-5 g) Fingers not numb compared to other runs |
| R.A. #6 | 31 Mar 98 | HAILSS | Y | 20 | 35 | <ul style="list-style-type: none"> a) Felt slightly unfocused during last set of cognitive tasks b) Rapidly moving eyes causes white "speckling" to appear c) Didn't feel as hot as in Mk 1 but felt more humid d) Suit started to feel cool towards end of run - "felt a cool breeze" through suit e) Head felt more humid in Mk 1 f) No puddling of suit in suit |
| M.K. #5 | 31 Mar 98 | HAILSS | Y | 20 | 35 | <ul style="list-style-type: none"> a) Severe pain in rear edge of ears b) Nothing different from other runs c) Bulk behind knees made pedalling difficult |
| HAILSS - 75% RH, cooled inlet air | | | | | | |
| R.N. #5a | 12 Jan 98 | HAILSS | Y | 75 | 24 | <ul style="list-style-type: none"> a) Felt like breathing in plastic bag (note: mask valve incorrectly set) b) AR5 ballooned out (fcn of mask) |

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| L.M. #1 | 14 Jan 98 | HAILSS | Y | 75 | 24 | <ul style="list-style-type: none"> a) Suit air felt VERY hot - AR5 air temp didn't noticeably change when entering chamber but HAILSS went from being "cool" to "very hot" when blower was turned on; run terminated because suit was "so hot and 10 min of exercise would make it that much hotter" b) Suit somewhat stiff during 1st exercise period loosened up during subsequent exercise periods c) Drinking water tasted bad d) Breathing air smelled foul - chemical or "gaseous" smell |
| R.N. #5b | 28 Jan 98 | HAILSS | Y | 75 | 24 | <ul style="list-style-type: none"> a) Feels sweaty, otherwise okay b) Chafing behind lateral right knee c) Face mask seemed to fit better d) Chafing feels like a sharp needle raking across tendon (suit examination suggests nylon liner or polyester mesh may be responsible) e) Torso felt hot but not sweaty, head felt okay but sweaty |
| M.L. #4 | 12 Feb 98 | HAILSS | Y | 75 | 24 | <ul style="list-style-type: none"> a) Sweating profusely b) No chills near end c) Legs extremely fatigued, muscles "burning" d) Buttocks irritated e) Mask applying pressure on nose, impaired nasal breathing f) Run stopped because of physical discomfort (see items c, d, and e) g) Slight claustrophobia h) Slightly lightheaded i) Felt cool air at midabdomen and lower back, felt good j) Cognitive performance impaired by sweat dripping into eyes k) Physical discomfort equivalent to previous runs but no sense of overheating |
| V.M. #5 | 13 Feb 98 | HAILSS | Y | 75 | 24 | <ul style="list-style-type: none"> a) Subject tolerated mask applying pressure on nose, helmet pressure on ears b) Cooling air <i>definitely</i> helped c) Didn't feel fatigued, felt like could have continued except for pressure (see a) d) Had no problem catching breath e) "Suit performed really well" f) Use large mask with bungee cord g) Pressure caused headache h) No problems with suit except for slight restriction at knees i) Felt cool air throughout suit (except head) j) Much less sweating k) Intercom system great in prep room but background noise was irritating in |

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| | | | | | | chamber l) Pressure first noticed when helmet and mask first put on and got progressively worse throughout run m) Sweat pouring out of sleeves |
| R.A. #2 | 5 Mar 98 | HAILSS | Y | 75 | 24 | a) Suit works well b) Felt cool in legs but not torso c) Slight headache, went away after drinking water d) "Hot spot" at lateral posterior left knee, "felt tight" e) This run felt "easier" than last run - especially pedalling - workload felt more constant than 1 st run (m75) f) Felt somewhat better than 1 st run, more stuffy g) Got lots of air through AR-5 |
| A.W. #5 | 25 Mar 98 | HAILSS | Y | 75 | 24 | a) Felt hotter from 2 nd run onward b) Felt cool air around shins with bent legs but at knees with bent legs during rest c) No sense of cool air when pedalling d) Hotter than last run (m75) but not as incapacitated (lightheaded) during cognitive tasks e) Slight headache and congestion when first entered lab f) Foot felt very hot where it touched bike pedal g) Last bike ride caused tingling in left toes h) Red mark on wrist maybe wrist compression i) No difficulty breathing j) Breathing air smelled of ammonia k) Wanted to drink after drinking tube fell out |
| M.K. #4 | 25 Mar 98 | HAILSS | Y | 75 | 24 | l) Ears hurt from mask cups m) Hands swollen and painful from wrist seals n) Neck seal constant nuisance o) Air made a difference - kept cool even though sweating p) Task monotonous (cognitive?), disgusting, and boring - not as motivated to excel q) Sick of answering questions r) Breathing air better than hose s) Bulk behind knees fatigues legs t) More comfortable than m75 overall but not legs u) Not cooler when pedalling |
| HAILSS - 75% RH | | | | | | |
| R.N. #1 | 8 Dec 97 | HAILSS | Y | 75 | 35 | Pinching at knees |
| V.M. #2 | 16 Jan 98 | HAILSS | Y | 75 | 35 | a) Felt lightheaded just before end of run - test stopped because subject didn't want to faint b) 2nd exercise bout exhausting but tolerable; cognitive tasks became |

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| | | | | | | <p>progressively more of an effort</p> <p>c) Couldn't seem to catch breath</p> <p>d) Breathing problems seemed to occur during cognitive testing but not exercise</p> <p>e) Hungry during testing</p> <p>f) HAILSS felt okay</p> <p>g) Felt cool air flow immediately upon entering prep room after run</p> <p>h) Felt like AR5 seal around chin was never good</p> |
| L.M. #3 | 27 Jan 98 | HAILSS | Y | 75 | 35 | <p>a) Stopped run because "it was so hot", heat felt suffocating</p> <p>b) Warm feeling started almost immediately upon entering chamber</p> <p>c) Mostly hot in head "face and mouth"</p> <p>d) Removing helmet felt instantly cooler</p> <p>e) Suit itself comfortable</p> <p>f) Mask fits better than in previous runs but is hotter</p> <p>g) Has trouble pedalling because of very low workload "pedals slip"</p> <p>h) Felt hot/wet inside suit compared with the last run feeling dry</p> <p>i) Maintained reasonable respirator seal</p> <p>j) Wore a retainer during run (did not during previous run)</p> <p>k) Use of nylon cloth tape left marks on legs for over 1 week, blunderm tape felt much better</p> |
| M.L. #3 | 29 Jan 98 | HAILSS | Y | 75 | 35 | <p>a) Felt chill down spine - from that point physiologically went downhill to exhaustion</p> <p>b) No problem with neck or wrist seals</p> <p>c) Rectal probe caused chaffing between buttocks cheeks - hurt when pedalling</p> <p>d) No suit bunching</p> <p>e) Sense of claustrophobia at end of run, breathing hard</p> |
| A.W. #1 | 10 Mar 98 | HAILSS | Y | 75 | 35 | <p>a) Left hand slight circulation problem "hand throbbled", index and thumb tingled, felt like falling asleep</p> <p>b) Suit felt fine but hot</p> <p>c) Last cognitive task harder to concentrate</p> <p>d) Slight tightness behind knees</p> <p>e) Toward end breathing became more labored</p> <p>f) Mask pressed on bridge of nose, slightly uncomfortable before entering chamber</p> <p>g) Mask leaked depending on head position</p> <p>h) Felt airflow in HAILSS immediately upon hooking into prep room blower - felt much better</p> <p>i) Felt air when first entering chamber but not not aware of it shortly thereafter</p> |

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| R.A. #5 | 24 Mar 98 | HAILSS | Y | 75 | 35 | <ul style="list-style-type: none"> a) Somewhat disorientated upon removing AR-5, unresponsive, confused b) Feels hot and cold c) Breathing hot air was uncomfortable, stuffy d) Appeared to have greater inspiratory resistance than other runs e) Felt head pressure but not headache smelled ammonia in mask |
| M.K. #6 | 6 Apr 98 | HAILSS | Y | 75 | 35 | <ul style="list-style-type: none"> a) hottest run b) AR-5 breathing air hot and stale – much hotter than previous runs |
| HAILSS - 75% RH, no AR5 | | | | | | |
| R.N. #2 | 10 Dec 97 | HAILSS | N | 75 | 35 | None |
| V.M. #1 | 16 Dec 97 | HAILSS | N | 75 | 35 | <ul style="list-style-type: none"> a) Need for head ventilation b) Airflow through breathing valve adequate but saliva a problem, "mouth too wet" |
| M.L. #2 | 26 Jan 98 | HAILSS | N | 75 | 35 | <ul style="list-style-type: none"> a) Felt sweating onset sooner than run #1 (Mk 75% RH) b) Didn't feel overheated yet experienced some nausea and lightheadedness c) AR5 more comfortable than 1-way mask and nose clip d) Felt heat sooner than run #1 (Mk 75% RH) and head felt hotter, took greater effort to pedal e) Breathing was greatest distraction f) wrist seal (especially right hand) caused hands to swell g) Rectal probe irritated back at level of coccyx |
| L.M. #4 | 19 Feb 98 | HAILSS | N | 75 | 35 | <ul style="list-style-type: none"> a) Run ended because subject very hot b) Subject felt instantly hot when blower hose attached in chamber and got progressively hotter c) Face and head slightly cooler than torso d) Head hotter with AR5 than without, otherwise no remarkable difference this and previous runs e) Feels suit is getting smaller, when first worn was huge but now almost snug f) No noticeable sweat marks on underwear |
| A.W. #2 | 12 Mar 98 | HAILSS | N | 75 | 35 | <ul style="list-style-type: none"> a) Suit felt hotter than 1st run (h75) – "noticed suit much more than last time" b) Bunched behind knees, no pain c) Finapres caused pain in fingers before readjustment d) Mask interfered with cognitive task e) Felt cool air enter suit somewhere around 2nd or 3rd pedalling f) Head felt cooler than 1st run (h75) |
| M.K. #1 | 17 Mar 98 | HAILSS | N | 75 | 35 | <ul style="list-style-type: none"> a) Breathing tube uncomfortable, felt like breathing stale air b) Forehead probe hurt, appears hair got |

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| | | | | | | stuck under tape c) "Suit was fine" d) Some rubbing on thigh e) Suit fit snugly, especially along torso – may not have been able to stand erect f) Slight nausea at end of test |
| R.A. #4 | 20 Mar 98 | HAILSS | N | 75 | 35 | a) Feels good, no headache – ready to continue b) "Suit was extremely comfortable" c) More comfortable than previous runs d) Shin Tc pulled off at some point in run |

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